Electrical Engineering

August
1936

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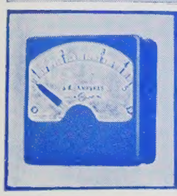
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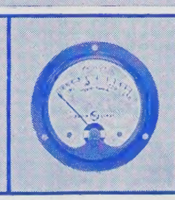
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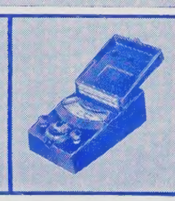
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430-67

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This Month—

Front Cover

[Lightning observatory on the roof of one of the General Electric Company's buildings at Pittsfield, Mass. The structure is 14 feet in diameter. In the center is a lighttight room in which storms can be observed by means of a 360 degree periscope which projects through the roof. A specially designed 12 lens camera is mounted directly underneath the platform for photographing lightning strokes.

Special Articles

A.I.E.E. Papers

—Turn to next page

The Measure of an Engineer

An address delivered before the annual business session of the 52d annual AIEE summer convention at Pasadena, Calif., June 22, 1936, by Vannevar Bush (A'15, F'24) Massachusetts Institute of Technology, Cambridge, in response to his receipt of the AIEE Lamme Medal for 1935 "for his development of methods and devices for application of mathematical analysis to problems of electrical engineering."

An engineer is called upon to be at once many different things. Certainly he must be something of a scientist, for it is the fruits of science that he is commissioned to apply. But he should be more than an applied scientist, for his application must fit into the complex affairs of civilization, and he is thus bound to be something of an economist, or man of business. Then too, we hear the demand, especially today, that he be fitted as sociologist and philosopher to guide his applications in such manner that the public may truly benefit. Finally, it appears that under some circumstances at least, he should be a bit of a politician in order that he may secure a chance to operate at all.

Nevertheless, the central function of the engineer is to apply science soundly. To do this most effectively it is necessary that he develop and utilize 2 contrasting mental attitudes.

The first of these is usually called analytical, and the second, practical. Both must be vigorously pursued and utilized in the full career of a professional engineer, with equal emphasis resulting in a proper balance. You may be sure that when an individual casts aspersions on either type of thought process, that individual himself is out of balance. The single point that I wish to make in this brief response is to emphasize the extent to which a true balance in this regard was attained by Lamme, and to impress upon the younger members of the profession that they cannot go far wrong if they pattern after him in this respect.

A word of elaboration, however, is necessary. By the analytical approach is meant much more than mere homage to theory. It involves the utilization of the scientific method in its broader sense; the breaking down of a problem of any sort into its elements; the recombination and elaboration of these by logical processes; the synthesis of observation and deduction into sound generalities; and the treatment of specific cases by careful identification of the governing laws. It involves the willingness to take pains, in order to be sure. It disowns superficiality and guesswork. It pays respect to the attainments of the past, and adopts the thought processes that have led others to great attainment, however difficult these may be to acquire: advanced mathematics, thermodynamical reasoning, dynamics, theory of electricity, and a host of other disciplines. Its keynotes are thoroughness and rigor.

Then too, by the practical approach is meant much more than the use of the handbook, the rule of thumb, or even of that unsystematized experience which is acquired by merely living a long time in the world. The truly practical man can operate when premises are incomplete and facts approximate, for he can weigh evidence, estimate probabilities, compare approximate analogies, and order history. Moreover, he can deal with human beings, perform under stress, and get things done. This attribute is harder to acquire with real proficiency than the former, and is usually best grasped by those who enter it from an early experience of rigorous thinking.

Both of these attributes are hardheaded, securely buttressed against wistful thinking or the enchantment of visionaries. Yet they are compatible with courage, a willingness to take justifiable risks, and an eagerness to support true progress.

Those of you who knew Lamme will recognize, as I draw this picture of my conception of the balanced engineer, that I am also painting the combination that made him a truly great engineer.

Much is demanded of engineers. That is why they are generally, as was Lamme, essentially modest. Being honest with their facts, they are also honest with themselves. They are inclined, perhaps too much inclined, to mind their own business. The title of "engineer" is as proud a title as any to which a man may aspire.

Effective Organization

By E. B. Meyer, President A.I.E.E. 1935–36

ALMOST everyone in our profession, I suppose, who has given thought to the matter, believes that the engineer should somehow take a larger part than the mere technical and supervisory rôle which has so largely characterized his activity. In addition to planning and executing in his specialized field it is said that he should have a more significant voice in determining the policies of our Institute.

This has been accomplished to a great extent through the decentralization of Institute management and affairs by giving a large degree of authority to Districts, Sections, and Branches. The organization of each District, Section, and Branch is so set up that individual participation in every phase of Institute activity is encouraged. Thus the ideas, opinions, and suggestions of each individual member are molded together to guide the officers and directors in carrying out their administrative functions.

The Institute as you know is divided into 10 geographical Districts, and these Districts are again divided into many Sections.

For the purpose of more effectively carrying out the aims of the Institute and for the convenience of the members, the Institute has provided for the organization of Sections. Sixty-one of these are now established in centers of electrical activity, and provision is made whereby 25 members may, by conforming to certain requirements, inaugurate a new Section.

These Sections, because of their local organization, which is similar to that of the parent body, and because their chairmen are affiliated in the Sections committee, are not only mutually helpful, but derive much direct assistance from the national organization. The chairmen, aided by the technical program committee of the Institute, in their local centers hold meetings of great interest to the members in their respective territories. In certain Sections, subgroups have been organized, such as power, transportation, illumination, and communication groups. They not only give opportunities for a wider range of meetings, but also permit the younger members to take more active parts in Section work. Thus there is brought within reach of all who desire to avail themselves thereof, opportunities for hearing, discussing, and presenting various papers relating to the immediate work of the individual or to the broader field of engineering, and all the advantages of contact with the ablest engineers in the profession.

In addition, many Student Branches have been established in the colleges and universities all over the country. Student Branches are organizations of students which have been established in institutions of learning by faculty members who are members of the Institute. These Branches, of which there are now 118, usually hold regular monthly meetings; they afford opportunities for independent activity and initiative on the part of students and for cultivating many of those qualities needed by the engineer that are not afforded by the classroom and laboratory, such as the preparation and presentation of papers on engineering topics not covered by classroom work, and which in many cases are better presented by individual students as a result of their own reading or investigation. They also give opportunities for social, technical, and literary activity. From among the A.I.E.E. members in the electrical engineering faculty of each college, the president of the Institute appoints a counselor to provide for continuity of Branch work. Provision has been made for an annual conference of the District officers and the counselors and chairmen of Branches in each geographical District to co-ordinate and develop the Branch activities.

I had the opportunity, during the past year, of visiting many of our Sections and Branches, and the expressions of interest in the Institute's problems and the loyalty to its purposes have truly been an inspiration to me.

After all, the officers, board of directors, and headquarters staff are only the means by which co-ordination is effected. It is the individual engineer who makes the Institute what it is—it is his Institute and the policies and codes formulated are merely reflections of his wishes.

The Institute has always been keenly interested in perpetuating an ideally democratic organization as opposed to dictatorship in any form or to any degree.

There is a great deal of thought being given this subject today, not only as applying to the government of peoples, but to all types of organizations as well.

Under dictatorship the authority resides in the highest officer. He grants a certain amount of control to officers next in command, who in turn delegate a less amount to lesser officers, and so on down the line until the great majority which has no authority is reached.

Under democracy the power of authority resides in the majority. It delegates a certain amount of authority to officers who are selected to serve the majority. In an organization of great size the democracy may take the so-called republican form. The smaller subdivisions of the democratic government elect delegates to represent them in a legislature or convention which formulates laws and nominates executive officers. Those elected direct from the subdivision may in turn elect delegates to meet with other such delegates from other subdivisions and so form a representative governing body for the whole.

The democratic idea is the highest ideal of government ever produced by man. It has never been fully realized, but as more people are able to understand the idea and as they outgrow the inferiority complex (which causes them to welcome the dictatorship of those inflated with their own assumed superi-

The president's message, presented at the opening session of the A.I.E.E. summer convention, Pasadena, Calif., June 22, 1936.

ority and strength) the more nearly we approach democracy.

In normal times when the interest of the majority appears to be clear, progressive results are obtained without great difficulty. In times of economic stress and political upheaval, there is apt to occur a situation that brings about an abnormal solution.

When the road is not plain, when a multitude of opinions widely differing are offered on which no agreement can be reached, or when no solution of the problem is forthcoming, then comes the possibility that one individual, dominating what may be only a small group, is placed in power. This power is due to chance, not qualifications, and comes through the inertia or lack of unity of thought among the other political elements.

In a democratic organization such as the Institute the rule is from below instead of from above. The officers and directors are elected by the majority either directly or indirectly and the members of the many committees are selected to give the widest possible spread of representation.

With the plan of organization into Districts, Sections, and Branches, such as we have developed, the possibilities of ineffectiveness through cumbersome, unnecessary, and impractical procedure are minimized. A directness of contact between officers and individual members has been maintained that has proved most desirable and beneficial. It is by reason of this policy of having members in even the most remote Sections actively engaged in the work of the Institute and in direct contact with its officers that the Institute is today such a vigorous organization.

The defeatist attitude and the willingness to surrender independence which has been so prevalent throughout the world has never touched the Institute, and it is today one of the most democratic organizations of which I have any knowledge.

In the face of the discouragements of the last 6 years the Institute has maintained its high professional standing, has carried forward its work through grave difficulties, and is now stronger than at any time in its history.

Over the years changes in administration have had no disturbing effect whatever on the smooth functioning of the Institute's many activities. The record of accomplishment supports this contention.

The work of the many Sections and Branches has been most effective and reflects the spirit of the membership in its desire to carry out every aim and purpose of our Institute.

With the realization of each member, first, that the American Institute of Electrical Engineers is his organization, and second, that the policies, objectives, and the conduct of its affairs, generally, are of his own making, continued progress is assured.

The past year has been one of great inspiration to me. I have been mindful of those who have been so willing—in fact, I should say eager—to co-operate with me in carrying out the many responsibilities entrusted to the office of president. I offer my sincere thanks and appreciation to all who have been directly associated with me and particularly to my fellow officers, the board of directors, committee personnel, and the headquarters staff.

The Tensor—A New Engineering Tool

The application of tensor analysis to the problems of electrical engineering results in a great simplification of the mathematics involved in such a complicated system as that of a rotating machine, for tensor analysis provides the ability to generalize from simple individual cases to complicated groups and systems. Originally, tensor analysis was developed as a tool in advanced geometrical analysis, but has since found extensive applications in other fields. The purpose of this paper is to point out the value of tensors, and to serve as an introduction to further study.

By
A. BOYAJIAN
FELLOW A.I.E.E.

General Elec. Co.
Pittsfield, Mass.

"I DO NOT think it is too extravagant to claim that the method of the tensor calculus . . . is the only possible means of studying the conditions of the world which are at the basis of physical phenomena"[1]—such is Eddington's enthusiastic and authoritative view of the value of tensor analysis in physics.

Originally, tensor analysis was developed by Ricci and Levi-Civita[2] as a tool in advanced geometrical analysis, but it has since found extensive applications to relativity and related field problems, elasticity, dynamics, etc. Its value as a tool in electrical engineering has been amply and beautifully demonstrated by Kron[3,4,5,6] by applications to rotating electrical machines and complicated static circuits.

Perhaps the major reason for the power and value of tensor analysis, at least from the standpoint of the electrical engineer, is its ability to generalize from simple individual cases to complicated groups and systems, and to deal with them wholesale. This it accomplishes in 4 ways.

First, by a remarkably comprehensive and yet simple notation and symbolism, tensor analysis makes manipulation of complicated systems very convenient. For instance, information that would ordinarily require many long rows of simultaneous

A paper recommended for publication by the A.I.E.E. committee on electrophysics, and tentatively scheduled for discussion at the A.I.E.E. winter convention, New York, N. Y., January 25–29, 1937. Manuscript submitted August 2, 1935; released for publication March 3, 1936.

1. For all numbered references see list at end of paper.

equations can be packed into a single short self-explanatory tensor equation. This feature of tensor analysis is so striking that some have been led to believe tensor analysis to be nothing but a mathematical shorthand. But, of course, tensor analysis is far more than a shorthand. The comprehensiveness of its notation is just a consequence of the comprehensiveness of its conceptions.

Second, by a method of analysis which is particularly adapted to generalization, tensor analysis automatically leads to the most generalized formulation of a problem. If an equation of the problem can be written for the simplest case with only one degree of freedom, in tensor form it becomes the formula for any number of degrees of freedom of the problem. For instance, Ohm's law for a single circuit expressed in tensor form becomes Ohm's law for all networks whether conductively connected or inductively coupled; the equation of a single coil moving in a magnetic field expressed in tensor form becomes the general equation for all rotating machines; the equation of a stationary line becomes the equation for all transmission systems; the equation of a crystal detector becomes that for all kinds of multielectrode vacuum tubes; etc. The full significance of this is brought home to the electrical engineer more clearly when he begins to see that, heretofore, every time he had a little different machine or a little different system, he had to start from the ground up to develop equations for each case, whereas tensor analysis enables him to write general equations applicable to all possible variations and elaborations of his machine or system.

Third, by a system of formulation which is independent of the type of units, co-ordinates, "measure codes," or system elements used, tensor analysis expresses generalized relationships in a universal language independent of specific points of view. This feature makes tensor analysis eminently suited for the formulation of the fundamental laws or relationships in nature. Those who are familiar with dimensional analysis will appreciate the significance of a system of formulation which is not only independent of the magnitude of the units of measurement but also is altogether independent of the system of measurement or co-ordinates or point of view. The electrical engineer comes to recognize the significance of this when he discovers that his equations have generally been based on specific co-ordinate axes (circuit terminals), and that every time his point of view changed, his equations have had to change; while his equations in tensor form remain unchanged no matter what new point of view and lines of approach (terminals) are followed to his system.

Finally, by certain generalized and standardized operations, tensor analysis makes the transformation of the specification of a problem from one set of co-ordinate axes to another a routine matter. The electrical engineer becomes keenly interested in this when he comes to see that, first, his circuit terminals or system elements are the co-ordinate axes of his problems, and second, that all his work in trying to determine one set of currents, voltages, or impedances from another set is nothing more than a transformation of co-ordinates; that is, a transformation of his system specification from one set of terminals or elements to another (equivalent) set of terminals or elements. For instance, the currents, voltages, and impedances of a given network can be specified either in terms of the external lines as one set of co-ordinate axes, or in terms of its internal branches as another equivalent set of axes. It is the same system, no matter from which point of view (set of leads) the currents, voltages, and impedances are specified; and, thus, it is seen that calculation of circuit and machine problems is nothing more than a transformation of co-ordinates and should be susceptible to conversion into a routine procedure.

Tensor as a Generalized Vector

In tensor analysis, vectors come in as a special class of tensors, from which it may be deduced that a tensor must be a generalized vector. But how may a vector be generalized? It can be indicated in 3 steps.

1. Generalized Vector Resolvable Into a Set of Independent Components

Stated broadly, a vector is a quantity resolvable into a set of independent components. The electrical engineer is familiar with vectors having components perpendicular to each other in space; he is familiar with vectors having components a quarter cycle apart in time. Perpendicularity of the components in space, or their separation by a quarter cycle in time, is merely a condition making the components independent of each other. Now, if the components are not restricted to space or time, and are not required to be mutually perpendicular or a quarter cycle apart, but if it is agreed to consider *any system of related but independent quantities* as constituting a vector, the first step in generalizing the vector concept has been taken.

If the field of interest of the electrical engineer is examined for quantities which have independent components or elements, which are not ordinarily considered as vectors but which it may now be desired to reconsider for admission into the status of generalized vectors, a number of them will be found.

a. Direct Currents and Voltages in a Network as Generalized Vectors. A d-c network comprising independent leads or circuits (co-ordinate axes) a, b, c . . . n, carrying the system of currents, i_a, i_b, i_c . . . i_n, respectively, and with voltages e_a, e_b, e_c . . . e_n, respectively, may be assumed. In accordance with the broadened conception of a vector, the network voltage may be considered, at least tentatively, as a generalized vector, and the branch voltages, e_a, e_b, etc., as its components, even though everything is direct current. Similarly, the network current may be considered as a generalized vector, and the line or branch currents, i_a, i_b, etc., as its components. In this example, the network itself has resolved the generalized vector into its components, so that the network current or voltage as a vector is not in evidence as a single quantity but only as a set of components.

The conception of the independent leads of a network as a set of co-ordinate axes of the network is one that should appeal to visualization and help fix the generalization. Co-ordinate axes in geometry may not be parallel, as otherwise they would not be independent; but the leads of a network may have any orientation in space whatever without affecting their independence of each other and, hence, their status as a reference system to define the current, voltage, and impedance components of the network.

b. System Voltage and System Current as Generalized Vectors. In an a-c system, say a polyphase system, the phase voltages (which need not be equal or symmetrical) are the components of the system voltage as a generalized vector; similarly, the phase currents are the components of the system current as a generalized vector. Here again the current and voltage vectors are in evidence not as a single entity but as a group of components. The difference between d-c and a-c quantities as generalized vectors is merely this: the components of a polyphase system are complex numbers, while those of a d-c system are real numbers.

c. Generalized Vectors in a Rotating Electrical Machine. Any kind of power is always associated with 2 quantities; one of the nature of pressure, the other of the nature of velocity or rate of displacement. If the total power of a system, such as a dynamo, is considered, and anything of the nature of pressure is tabulated in one group, voltages in the windings and torque in the rotor are found which may be considered as the components of the generalized pressure vector of the dynamo. Similarly, the currents in the windings (field and armature) and the velocity of the rotor are found as the components of a generalized velocity vector of the dynamo. Here are, tentatively at least, 2 strange vectors, each one with mixed electrical and mechanical components. It reminds one of the relativists' "interval vectors" of which 3 components are space and 1 component is time. The scalar product of the pressure vector with the velocity vector gives the net power developed by the dynamo, which fact alone is sufficient justification for grouping together electrical and mechanical quantities as the components of one vector.

d. Simultaneous Equations as Equations Defining the Components of a Generalized Vector. The electrical engineer is familiar with the fact that a vector equation like

$$e = F(x, y, z) \tag{1}$$

is always equivalent to a set of simultaneous scalar equations, one for each component:

$$\begin{aligned} e_1 &= F_1(x, y, z) \\ e_2 &= F_2(x, y, z) \\ &\cdots\cdots\cdots\cdots \end{aligned} \tag{2}$$

the components e_1, e_2, etc., being pure numbers. With the aid of the generalized vector concept, any set of simultaneous equations like equations 2, may be considered as the equations defining the components of a vector like equation 1. Thus, to constitute a generalized vector, the set of quantities $e_1, e_2 \ldots e_n$ (equation 2) need not represent a physically directed quantity in space, nor a harmonic quantity in time; in fact, it is not necessary to know what physical quantity they represent, in order to decide whether or not they constitute a generalized vector. They may be considered, at least tentatively, as constituting a generalized vector if they are simultaneously true, that is, if they constitute one group or system of related but independent quantities.

Can the status of these tentative vectors be settled definitely? For this, further characteristics of well-known vectors must be examined.

2. Generalized Vector as a Covariant or a Contravariant Quantity

Criterion of a Vector. Inasmuch as resolvability into components is the most conspicuous characteristic of a vector, the difference between a vector and a nonvector (which also might conceivably be resolvable into components in some sense) must be looked for in some possibly characteristic manner in which a vector is resolved into components in various reference systems, and the characteristic manner in which these components are altered when the reference system is altered. In other words, the criterion of a vector must be sought in its transformation characteristics.

If the behavior of familiar vectors is studied under a change in the reference system, 2 distinct types are found, one exemplified by a displacement vector, the other by a gradient vector. The transformation formulas of these 2 types are inverse or reciprocal to each other.

To illustrate this by an elementary case, there may be considered the simplest possible transformation of co-ordinates, namely, a change of scale, say from inches to centimeters. A 10 inch displacement vector then becomes a 25 centimeter displacement vector; while a 10 degree centigrade per inch gradient vector becomes, not 25, but only a 4 degree centigrade per centimeter gradient vector. That is, vectors of the type of displacement and vectors of the type of gradients become transformed in inverse fashion to each other. Vectors which like gradients become smaller when the system units are made smaller, are appropriately called *covariant* and are marked by a subscript as in

$$g_m = g_x, g_y, g_z \tag{3}$$

while those, which like displacement, undergo reciprocal transformation are called *contravariant*, and are marked by superscripts, as in

$$d^m = d^x, d^y, d^z \tag{4}$$

The index m is understood to be a variable co-ordinate, assuming successively the specific values x, y, z, etc.

The position, too, of the indices in the 2 types of vectors will be seen to be appropriate, when it is remembered that the vector with the superscript (like a displacement of 10 unit vectors) has its unit vector in its numerator, while the one with the subscript (like a gradient of so many degrees per unit vector) has its unit vector in the denominator.

In fact, the indices may be looked upon as unit vectors, in the numerator if superscripts, in the denominator if subscripts.

*Whatever the change in the reference system, the components of a covariant vector undergo a change proportional (vectorially) to the change in the unit vectors of the system, while the components of a contravariant vector undergo the inverse change.**

This is the necessary and sufficient condition that a given system of quantities qualify as the components of a generalized vector or tensor. Groups of quantities which follow other laws of transformation are not tensors.

In order that the foregoing criterion of a vector may not appear as artificial or purely mathematical, it may be desirable to point out its physical basis and interpretation. The identity and characteristics of a vector in itself have nothing to do with co-ordinate axes: the vector in itself is an invariant quantity, but the components of the vector are functions of the co-ordinate axes. Now there are other things besides vector components which also are functions of the co-ordinate axes and which do not represent an invariant quantity. Whether or not a given set of quantities expressed as functions of the co-ordinate axes represents an invariant quantity like a vector can be ascertained mathematically only by changing the co-ordinate system and observing how the given set transforms: those which transform in accordance with the above represent an invariant quantity, others do not.

It may be worth while now to apply this criterion to some provisional tensors.

Voltage as a Covariant Tensor and Current as a Contravariant Tensor. The well-known analogy between current and voltage would naturally lead to setting down current as a contravariant tensor; and that between voltage and pressure, to setting down voltage as a covariant tensor. In fact, in electromechanical systems such as rotating electrical machines exhibiting in one tensor both velocity and current components, or both pressure and voltage components, the contravariance of current and the covariance of voltage are no more a matter of analogy but one of necessity.

These characteristics of current and voltage can also be seen easily in a co-ordinate transformation as follows: It has been explained that the terminals of a network are its co-ordinate axes, and a change in their arrangement or connections constitutes a change in the co-ordinate system of the network. If 2 similar circuits are in parallel, and are reconnected in series, changing the system terminals (the co-ordinate axes) thereby but without changing the power involved, the line voltage is found to be doubled and the line current to be halved, indicating that one quantity is covariant, the other contravariant. If the system is alternating current, and it is transformed through a static transformer, the voltage is found to increase directly with the turns, the current inversely: which again shows that of current and voltage one is covariant, the other contravariant. If the circuit equations do not involve mechanical components, it does not matter then whether the current or the voltage is designated as the covariant or contravariant quantity.

If the system is polyphase, and changed from delta to wye, it is found that the system voltages are multiplied by 1.73, the system currents divided by 1.73, etc., as further confirmation of voltages and currents being covariant and contravariant vectors, respectively.

It is even more striking to observe that in an unsymmetrical polyphase system, or any unsymmetrical network, the current and voltage systems transform inversely to each other. The reciprocal relationship is not a narrow one as between individual components of current and voltage, but a generalized one as between the systems of currents and voltages. Tensor analysis defines the meaning of this and the method of its calculation.

The reader may comment that, in any circuit transformation, the law of conservation of energy compels current and voltage to vary inversely, so as to leave the power unchanged. To that should be added the following: the "invariants" of tensor mathematics represent such things as energy which are "conserved" in any transformation, and the "covariance" and "contravariance" of tensor components are the mathematical manifestations of the mechanism which insures the mathematical "invariance" of the physical invariants. For instance, with voltage as a covariant vector

$$e_m = e_a, e_b, e_c \ldots \tag{5}$$

and current as a contravariant vector

$$i^m = i\ , i^b, i^c \ldots \tag{6}$$

the equation for the power, p, is

$$p = \Sigma e_m i^m \tag{7a}$$

$$= e_a\, i^a + e_b\, i^b + e_c\, i^c + \ldots \tag{7b}$$

Now, if it is remembered that indices may be regarded as unit vectors (superscripts as unit vectors in the numerator; subscripts, in the denominator), it is realized that each term in equation 7*b* is a constant independent of the co-ordinate axes, because the indices of each term cancel out, and no reference to co-ordinate axes is left in the final result.

3. Generalized Vector as a Multidimensional Quantity

As a final step in generalization, vectors of the type of impedance may be considered. What kind of tensor may impedance be?

If the impedance elements of a network a, b, c, etc., are tabulated in a symmetrical fashion, there is obtained a 2-dimensional array like

$$Z_{ik} = \begin{cases} Z_{aa}, Z_{ab}, Z_{ac} \ldots Z_{an} \\ Z_{ba}, Z_{bb}, Z_{bc} \ldots Z_{bn} \\ Z_{ca}, Z_{cb}, Z_{cc} \ldots Z_{cn} \\ \ldots \quad \ldots \quad \ldots \quad \ldots \\ Z_{na}, Z_{nb}, Z_{nc} \ldots Z_{nn} \end{cases} \tag{8}$$

In contrast with current and voltage vectors whose

* Mathematical formulation of this definition is omitted here as of relatively little help to the beginner, especially to the engineer. It will be found in the references at the end of the paper.

components form 1-dimensional arrays (equations 5 and 6) and have the same number as the coordinate axes (terminals), the impedance components form a 2-dimensional array and their number is equal to the square of the number of the coordinate axes. The reason for the difference will be found in the important fact that while current or voltage components involve 1 circuit at a time, each impedance component involves 2 circuits—either 2 different circuits as in Z_{ab}, or the same circuit twice, as in Z_{bb}, etc. What may this mean?

If familiar vectors are examined for a clue as to the significance of this, it is found that some of them, like displacement, velocity, force, and gradient, are 1-dimensional quantities; while some others, like area, torque, angular velocity, etc., are really 2-dimensional quantities, even though in conventional vector analysis they are treated as 1-dimensional vectors by the artifice of representing them by their complementary dimension (the dimension which they lack). In space with more than 3 dimensions, or in problems with more than 3 independent variables, this artifice fails, and it is not possible to represent an area as a 1-dimensional vector because in 4-dimensional space an infinite number of perpendiculars, not parallel to each other, can be drawn to a given area; nor can torque or rotation be represented by an arrow as its axis, because the axis of rotation in 4-dimensional space is an area, not a line; nor can impedance be represented as a single circuit impedance in networks with more than 3 elements; but each component of these quantities must be defined by the 2 dimensions, axes, circuits, or terminals which it involves.

Generalizing from the foregoing, it may then be recognized that *a generalized vector or tensor can be of any number of dimensions*, and that the common vector is merely a special case as a 1-dimensional tensor, or a tensor of rank one, while impedance and area are tensors of rank 2.

It is important to observe that what makes an impedance a tensor of rank 2 is not the fact that it may involve both resistance and reactance, but the fact that each component of it involves 2 circuits. A pure resistance network is a tensor of rank 2 with real components; a pure reactance network, a tensor of rank 2 with quadrature components; an impedance, a tensor of rank 2 with complex components, as in

$$Z_{jk} = \begin{cases} (R_{aa} + jX_{aa}), \ (R_{ab} + jX_{ab}), \ \dots \\ (R_{ba} + jX_{ba}), \ (R_{bb} + jX_{bb}), \ \dots \\ \dots\dots\dots\dots\dots\dots\dots\dots \end{cases} \qquad (9)$$

Test of Impedance as a 2-Dimensional Tensor

To make certain that these superficial analogies have not been misleading, it may be well to subject impedance to the test of covariance or contravariance, for tensors of any rank must be one or the other in each dimension or circuit they involve. For instance, T_x^y is covariant in the x and contravariant in the y variables; T_{xy} is covariant in both the x and y variables; T^{xy} is contravariant in both the x and y variables.

If a 2-dimensional tensor is covariant in both indices, it is going to be doubly covariant compared with a simple covariant vector. Whether or not this holds true about impedance will now be investigated.

In changing 2 similar elements from parallel to series connection it was found that the voltage at the line terminals is doubled, and it may be verified that the resistance (or impedance) at the line terminals is quadrupled.

In changing a given circuit through a static transformer into another equivalent circuit, the effective impedance is automatically transformed as the square of the voltage.

In changing from wye to equivalent delta, the phase voltages become multiplied by 1.73; the phase impedances, by 1.73 times 1.73.

These elementary examples show that the impedances of an electrical system are covariant like the voltages, and doubly so; that is, they are covariant tensors of rank 2 with 2 true tensor subscripts as in equation 8.

The electrical engineer always knew that there was some difference between voltage as a vector and impedance as a vector, but he was never very clear about the difference. Sometimes he called one a vector, the other an operator; but there was absolutely nothing in his complex quantity equations even to hint at a difference in their nature. Tensor analysis brings this out clearly and beautifully.

Simple Examples of Tensor Equations and Operations

Ohm's Law. The well-known formula $e = iZ$, which contemplates a single circuit, becomes the equation of any complicated system of circuits, regardless of their connections, if written in the tensor form

$$e_m = i^n Z_{mn} \qquad (10a)$$

where m and n are variable indices.

Equation $10a$ stands for a set of ordinary simultaneous equations like

$$\begin{aligned} e_1 &= i^1 Z_{11} + i^2 Z_{12} + i^3 Z_{13} + \dots \\ e_2 &= i^1 Z_{21} + i^2 Z_{22} + i^3 Z_{23} + \dots \\ e_3 &= i^1 Z_{31} + i^2 Z_{32} + i^3 Z_{33} + \dots \\ &\dots\dots\dots\dots\dots\dots \end{aligned} \qquad (10b)$$

The superb compactness of equation $10a$ over $10b$ will be obvious enough, but it may not be obvious that this compactness is a natural consequence of the tensor conceptions and not one of arbitrary definition. One might consider equation $10a$ as a representative equation to be used as a guide in the writing of the complete set of equations like equation $10b$, but such a view would be inadequate to the broader tensor concept: *equation 10b is a system of equations; 10a, the equation of a system.* If one cannot think of a network except as a collection of impedances, with emphasis on the plurality of the elements, equation $10b$ is his natural language; but when one rises to the conception of a network as a single system, equation $10a$ becomes his logical language.

But why should not equation $10a$ have a summa-

tion sign as in equation 10c?

$$e_m = \Sigma i^n Z_{mn} \tag{10c}$$

One reason is that, so far as numerical work is concerned, the duplication of n in superscript and subscript already contains the summation concept implicitly, and therefore a big sigma in front would be a superfluity. A second reason is that such a sign would interfere with the unity of the conception and therefore with the solution or manipulation of equation 10a. We might explain this second reason first.

Solution of Tensor Equations. Equation 10a for the system voltage can be solved for the system current by an obvious transformation, giving

$$i^n = e_m(Z_{mn})^{-1} \tag{11a}$$
$$= e_m Y^{nm} \tag{11b}$$

The solution states that the system current is equal to the system voltage times the system admittance, and that the system admittance is the reciprocal of the system impedance. Now, if a routine method is available (as it is) for finding the reciprocal of an impedance tensor, then the solution is complete and elegant. This is a good illustration of what was meant hereinbefore by speaking of dealing with groups or systems *wholesale.*

Considering equation 10c now, there is no obvious way of solving it; Z_{mn} cannot be transferred to the other side of the equation past the big sigma at the entrance of the right hand term. Considering equation 10b, the problem is one of solving a set of simultaneous equations. It can be done, of course; and enough simultaneous equations have been solved by mathematicians to enable them to see the swing of it and thereby systematize the procedure by the method of determinants.

Granting that the calculation of the reciprocal of the impedance in equation 11a must involve some or equal labor for numerical work, the directness and conciseness of the tensor method, with its economy of thought, memory, and paper, may still be appreciated. This also illustrates what was meant earlier in this paper by tensor methods resolving the calculation of specific cases into a routine procedure.

Dimensional Balance of a Tensor Equation

It may be interesting and instructive to observe the dimensional balance of equation 10a. If it is remembered that indices may be looked upon as unit vectors (or dimensional units), it may be seen that the 2 n's in equation 10a, one as superscript and the other as subscript, cancel, leaving only the dimension m on both sides. All tensor equations are dimensionally balanced.

Application to the Summation Convention

To show how the foregoing understanding clarifies the basis of the summation convention discussed in the earlier paragraph, equation 10a may be again taken as a start. Inasmuch as m and n are variable indices, with the only explicit restriction that whatever value is assigned to n in i^n, the same value must be assigned to n in Z_{mn}, the equation may be written for circuit k as

$$e_k = i^a Z_{ka}, i^b Z_{kb}, i^c Z_{kc} \ldots \tag{12}$$

The items listed on the right hand side of this equation *combined* constitute the voltage of circuit k. How do they combine? When the dimensions of these constituent terms are considered, it is seen that they are all homogeneous and have only the dimension k, since the a's cancel, b's cancel, etc. Having identical dimensions, these constituent terms are like parallel vectors and combine algebraically; and, therefore, this fact may be recognized explicitly by replacing the commas in equation 12 with plus signs. In other words, summation is implicit in equation 10a by the repetition of the same index in superscript and subscript, and therefore no summation sign is necessary.

The Multicircuit Transformer

A multicircuit transformer may now be considered, and one of the windings selected as the reference circuit like a primary. Let Δe_m represent the vectorial voltage regulation of the mth winding; i^n the current in the nth winding, and Z_{mn} the mutual impedance between the 2 circuits for load currents as understood by those familiar with the theory of 3 circuit transformers. Then

$$\Delta e_m = i^n Z_{mn} \tag{13}$$

Under short-circuit conditions Δe_m and Z_{mn} would be given, and i^n would be required to be solved for the various circuits. Solving equation 13 for i^n,

$$i^n = \Delta e_m(Z_{mn})^{-1} \tag{14a}$$
$$= \Delta e_m Y^{nm} \tag{14b}$$

The formal solution of the short-circuit currents of a multicircuit transformer is thus carried out in an elegantly simple manner compared with the usual method of simultaneous equations. What at the outset would have appeared to many as a formidable problem turns out to be nothing more than the solution of Ohm's law as in equations 10 and 11, and that the numerical calculation of the short-circuit currents of a multicircuit transformer is nothing more than the routine matter of calculating the reciprocal of an impedance tensor and making a multiplication.

Transformation Tensors

Let i^m, with English indices, be the component currents of a system as referred to an appropriate set of axes (say the internal branches of a network, circuits of a transformer, or windings of a machine) as

$$i^m = i^a, i^b, i^c \ldots \tag{15}$$

and let i^λ, with Greek indices, be the component currents of the same system referred to another equivalent set of axes (for instance, the external terminals of the system)

$$i^\lambda = i^\alpha, i^\beta, i^\gamma \ldots \tag{16}$$

Given the diagram of connections or physical structure of the system, equations can be written for i^λ in terms of i^m like

$$\begin{aligned} i^\alpha &= C_a^\alpha i^a + C_b^\alpha i^b + C_c^\alpha i^c + \ldots \\ i^\beta &= C_a^\beta i^a + C_b^\beta i^b + C_c^\beta i^c + \ldots \\ i^\gamma &= C_a^\gamma i^a + C_b^\gamma i^b + C_c^\gamma i^c + \ldots \\ &\ldots\ldots\ldots\ldots \end{aligned} \tag{17}$$

in which the C_m^λ type quantities may be regarded for the present as coefficients with indices indicating clearly to what term they belong.

It was pointed out in connection with equation 2 that a system of independent simultaneous equations can be considered as the equations of the components of a single vector, so that equation 17 can also be written as

$$\begin{aligned} i^\lambda &= F(i^m) \\ &= F(i^a, i^b, i^c \ldots) \end{aligned} \tag{18}$$

If it is desired to indicate the form of the function F more explicitly, an inspection of equation 17 will show that it can be written as

$$i^\lambda = \sum_{m=n}^{m=n} i^m C_m^\lambda \tag{19}$$

or, omitting the superfluous summation sign as explained previously,

$$i^\lambda = i^m C_m^\lambda \tag{20}$$

The quantity C_m^λ obviously can be tabulated in a logical order constituting a square array as shown below, by an inspection of equation 17:

$$C_m^\lambda = \begin{matrix} C_a^\alpha, C_b^\alpha, C_c^\alpha \ldots \\ C_a^\beta, C_b^\beta, C_c^\beta \ldots \\ C_a^\gamma, C_b^\gamma, C_c^\gamma \ldots \end{matrix} \tag{21}$$

Equation 21 makes C_m^λ look like a tensor of rank 2. Is it? If so, is it covariant in one index, and contravariant in the other, as indicated?

This could be answered by the test of covariance and contravariance but a neater method of deciding this matter is by the dimensional balance of the tensor equation.

If equation 20 is a true and complete tensor equation, its dimensions must balance; and it may be seen that they do, if C_m^λ is a tensor, and λ and m are true tensor indices; for then the m in the superscript of i^m cancels the m in the subscript of C_m^λ, leaving λ as the net dimension on either side of the equation.

The conclusion is that the transformation operator changing the components of a vector from one system of reference axes (terminals) into another, is a tensor of rank 2, like C_m^λ, covariant in one index, contravariant in the other.

Again, lest one think that the superbly compact tensor equation 20 is nice but nothing more than a mere shorthand guide for the writing of a set of simultaneous equations, the following paragraphs will indicate what remarkable results can be derived from it in a "conservative" transformation without formally bothering with any set of simultaneous equations. By conservative transformation is meant any circuit transformation, whether physical or just paper transformation, in which the power is invariant, as for instance, delta-wye transformation, series parallel transformation, transformations by static transformers (ignoring the losses), network to terminal transformations, machine coils to machine terminals transformations, symmetrical components, etc. Most of the analytical problems of electrical engineering are of this type, and many of the others can be brought into this form by suitable devices.

Transformation Tensors of Currents, Voltages, and Impedances

Let e_λ be the system voltage referred to the Greek lettered axes or connections, e_m the same system voltage referred to the English lettered axes or connections, the latter being transformed to the former by the transformation tensor or matrix C_λ^m, as in

$$e_\lambda = e_m C_\lambda^m \tag{22}$$

If now it is desired to determine how the system current i^m and the system impedance Z_{mn} transform with reference to the new (Greek lettered) terminals or connections into i^λ and $Z_{\lambda\mu}$, respectively, it is not necessary to start from the ground up and develop equations for each anew. Since the system current must transform inversely as the system voltage, and the system impedance as the square of the system voltage, their transformation equations can be written at once as

$$i^\lambda = i^m (C_\lambda^m)^{-1} \tag{23a}$$

$$= i^m C_m^\lambda \tag{23b}$$

and

$$Z_{\lambda\mu} = Z_{mn} C_\lambda^m C_\mu^n \tag{24a}$$

$$Y^{\lambda\mu} = Y^{mn} C_m^\lambda C_n^\mu \tag{24b}$$

The problem is solved formally in equations 23 and 24, and the numerical work is reduced to routine calculation of the reciprocal of a matrix and tensor multiplication.

For further examples and applications, also for the details of tensor operations, the reader must be referred to the sources listed below, especially reference 4. It is hoped that the foregoing informal presentation may enable the reader to gain a practical insight into the spirit, concepts, and value of tensor analysis, and that he may acquire thereby a desire and preparation to follow it up further.

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Professional Aspects of Engineering Education

First results of the 1935 survey of the status of the engineering profession conducted by the Bureau of Labor Statistics of the United States Department of Labor at the request and with the co-operation of American Engineering Council.

READERS of ELECTRICAL ENGINEERING may recall having filled out early in 1935 a questionnaire concerning their professional experience and status, prepared by the United States Bureau of Labor Statistics, Dr. Isador Lubin, Commissioner, at the request and with the co-operation of the American Engineering Council. In the *Monthly Labor Review* for June 1936, the first results of this survey of the engineering profession are presented in an article entitled, "Educational Qualifications in the Engineering Profession," prepared by Andrew Fraser, Jr., of the Bureau's division of wages, hours, and working conditions. This is the first of a series of summary articles covering results of the survey, and through the courtesy of Dr. Lubin, a résumé of Mr. Fraser's article, and excerpts from it, are here presented.

Table I—Geographical Distribution of the 9 Major Professional Classes of Engineers

Professional Class	Total	Geographical Division: District of Columbia	East South Central	Mountain	West South Central	South Atlantic	New England	West North Central	Pacific	East North Central	Middle Atlantic
United States	52,589	948	1,544	2,434	2,486	3,920	4,674	4,978	5,651	10,977	14,977
Agricultural	397	9	21	20	36	38	10	123	38	71	31
Architectural	538	10	8	20	22	29	44	107	30	139	129
Ceramic	388	3	11	2	5	22	10	38	26	169	102
Chemical	3,512	37	107	108	213	291	369	296	179	878	1,034
Civil	19,891	450	707	1,191	1,082	1,619	1,631	2,295	3,099	3,244	4,523
Electrical	11,443	195	286	385	489	856	1,080	991	920	2,412	3,829
Industrial	1,007	6	19	14	18	76	129	56	44	270	375
Mechanical	13,226	197	320	285	548	898	1,313	884	986	3,343	4,452
Mining and Metallurgical	2,187	41	65	409	73	91	88	188	329	401	502

General Conclusions

The general conclusions as to educational qualifications in the engineering profession are stated by Mr. Fraser as follows:

A first degree in engineering is now almost a prerequisite in order to obtain professional status and a position. Postgraduate work, however, is important only in a few of the professional classes. The tendency of engineers to transfer from the course of college specialization to other classes of work is negligible. These are a few of the facts developed in the survey of the engineering profession, which was undertaken by the Bureau of Labor Statistics in May 1935, at the request of the American Engineering Council.

Scope and Method

In order to make clear the purpose, scope, and methods of the survey, it is convenient to quote the following passages from Mr. Fraser's article:

The principal purpose of this survey was to determine how the engineers fared during the depression period. More specifically, the objectives were to determine the extent of unemployment, what kind of professional employment gave engineers the greatest protection against unemployment, where they found substitute employment, and their compensation between December 31, 1929, and December 31, 1934. However, to provide a comprehensive background for these data, the survey was extended to include the salient features of education and subsequent experience, so that the nature of the general trends affecting the profession could more readily be determined. Unquestionably, a knowledge of trends is of inestimable value to administrators of professional engineering education and to the practicing and prospective engineer.

The data were obtained through the medium of a mail questionnaire, requesting information, for the three periods ending December 31, 1929, 1932, and 1934, on: Present city and state residence; marital status and number of dependents; type of education; employment; unemployment; earnings; membership in engineering societies; method of obtaining employment, together with information on contract, patent, and civil-service privileges; field of activity; functional classification; and professional class. A copy of this questionnaire was sent to each of 173,151 engineers.

The mailing list for the questionnaire was compiled for the Bureau through the co-operation of national, state, and local engineering societies, and additional names were obtained from 32 state boards of engineer examiners and the deans of 156 engineering schools. At the time the requests for names were issued, there were known to be in existence 80 national, 42 state, and 197 local societies, and of these respectively 73, 39, and 121 submitted names from their past and present membership rosters. Obviously, since the co-operating bodies embraced every phase of professional activity, the original mailing list, from which duplications were eliminated, can be accepted with little question as being adequate.

Essential substance of an article published on pages 1528–42 inclusive of *Monthly Labor Review*, v. 42, No. 6, June 1936; obtainable from the Superintendent of Documents, Washington, D. C., at 30¢ per copy. Abridgment prepared by Editor George A. Stetson of the American Society of Mechanical Engineers; published in ELECTRICAL ENGINEERING upon recommendation of the A.I.E.E. Committee on Education, and with the approval of Commissioner Isador Lubin of the U.S. Bureau of Labor Statistics.

Type of Education	Agricultural No.	Agricultural Per Cent of Total	Agricultural Per Cent of Professional Class	Architectural No.	Architectural Per Cent of Total	Architectural Per Cent of Professional Class	Ceramic No.	Ceramic Per Cent of Total	Ceramic Per Cent of Professional Class	Chemical No.	Chemical Per Cent of Total
Engineering Graduates											
Course same as professional class:											
1....First degree in engineering	201	82.4	50.6	338	94.2	62.8	294	90.2	75.8	2,488	84.3
2......Engineering only	200	82.0	50.3	329	91.7	61.2	289	88.7	74.5	2,385	80.8
3......Engineering, plus B.A.	1	0.4	0.3	9	2.5	1.6	4	1.2	1.0	89	3.0
4......Engineering, plus M.A.							1	0.3	0.3	6	0.2
5......Engineering, plus Ph.D.										8	0.3
6....Master's degree in engineering	42	17.2	10.5	21	5.8	3.9	30	9.2	7.7	363	12.3
7......Engineering only	42	17.2	10.5	21	5.8	3.9	30	9.2	7.7	360	12.2
8......Engineering, plus B.A. in liberal arts										3	0.1
9......Doctor's degree in engineering	1	0.4	0.3				2	0.6	0.5	100	3.4
10........Total	244	100.0	61.4	359	100.0	66.7	326	100.0	84.0	2,951	100.0
Course different from professional class:											
11....First degree in engineering	97	87.4	24.5	38	97.5	7.1	15	75.0	3.9	121	84.0
12......Engineering only	92	82.9	23.2	38	97.5	7.1	14	70.0	3.6	117	81.2
13......Engineering, plus B.A. in liberal arts	4	3.6	1.0				1	5.0	0.3	4	2.8
14......Engineering, plus M.A. in liberal arts	1	0.9	0.3								
15......Engineering, plus Ph.D. in liberal arts											
16....Master's degree in engineering	14	12.6	3.5	1	2.5	0.2	5	25.0	1.3	19	13.2
17......Engineering only	14	12.6	3.5	1	2.5	0.2	5	25.0	1.3	18	12.5
18......Engineering, plus B.A. in liberal arts										1	0.7
19....Doctor's degree in engineering										4	2.8
20........Total	111	100.0	28.0	39	100.0	7.3	20	100.0	5.2	144	100.0
Other Engineers											
21..Nonengineering graduates	13		3.2	36		6.7	16		4.1	212	
22..Engineering graduates (with other degrees) in nonengineering fields	1		0.3							23	
23..College engineering course, unfinished	17		4.3	67		12.5	16		4.1	154	
24..Noncollegiate technical-school engineers	5		1.3	26		4.8	5		1.3	20	
25..Secondary-school engineers	6		1.5	6		1.1	5		1.3	3	
26..Total	42		10.6	135		25.1	42		10.8	412	
27..Total, not reporting				5		0.9				5	
28......Grand total	397		100.0	538		100.0	388		100.0	3,512	

Of the 173,151 questionnaires sent out, 58,388, or 33.7 per cent, were returned with information; 5,883, or 3.4 per cent, were returned as "not found"; and no replies were received from 108,880, or 62.9 per cent. The net number of usable returns was 52,589, or 30.4 per cent of the number of persons on the original mailing list, a most gratifying response, especially in view of the fact that no follow-up method was used.

Table I summarizes the results of the survey on the basis of the geographical distribution of the nine major professional classes into which the engineers replying to the questionnaire were grouped.

Nature of Educational Data

Regarding the nature of the educational data sought and classified, Mr. Fraser says:

Since education is closely related to professional activity, information on this point was the first to be compiled for analysis.

At the outset, it should be remarked that no specific information was requested in this survey concerning curricula in education. The only questions asked were with respect to the particular type of education received, and these types embraced secondary school, noncollegiate technical school, university, or college, including nongraduate, graduate, and postgraduate work. In each case, the questionnaire called for the number of years of attendance, the name of the institution, the course taken (whether liberal arts, civil engineering, etc.), and the date of graduation. Nevertheless, as there is a close relation between curricula and type of education, there is some justification for using the latter as a basis for analysis, especially since by so doing there is the decided advantage of obtaining a broad picture of the situation, which of course facilitates the subsequent analyses.

With more particular reference to trends, this article is concerned with (1) the prevalence of first degrees in engineering, (2) the extent of postgraduate work, (3) the tendency of engineers to transfer from the course of specialization to other professional fields, (4) the nature of the distribution as between all graduates and nongraduates of "other engineers," and (5) the general relation of education to fields of activity and functional classification.

College Training in Engineering

The distribution of the nine professional classes by type of education in the country as a whole, as of 1934, is shown in table II. Engineers reporting were divided into 2 groups, one including engineering graduates, i. e., those who reported having obtained an engineering degree from a college or university, and other engineers, i. e., all those who received a secondary-school, noncollegiate, nongraduate, or nonengineering education.

Engineering graduates, Mr. Fraser explains, are in turn divided into 2 groups, "graduates whose professional class is the same as the college course in which they specialized and those whose professional class is different from the specialized college course. From this arrangement," he continues, "the importance of first degrees and of postgraduate work in engineering may be determined, first, with reference to the graduate group as a whole, and second, as related to the grand total reporting in each professional class." It is clear from the tabulation that in each professional class as a whole the number of men with first degrees only strongly predominates.

gineers, in the United States, 1934, by Type of Education

Professional Class—Continued																		
Civil			Electrical			Industrial			Mechanical			Mining and Metallurgical			Total			
o.	Per Cent of Total	Per Cent of Professional Class	No.	Per Cent of Total	Per Cent of Professional Class	No.	Per Cent of Total	Per Cent of Professional Class	No.	Per Cent of Total	Per Cent of Professional Class	No.	Per Cent of Total	Per Cent of Professional Class	No.	Per Cent of Total	Per Cent of Professional Class	
,302	94.6	61.9	8,460	91.7	73.9	403	95.9	40.0	8,390	94.1	63.4	1,366	89.4	62.5	34,242	92.6	65.1	1
,884	91.3	59.8	8,165	88.4	71.4	389	92.6	38.6	8,174	91.7	61.9	1,283	84.0	58.8	33,098	89.5	62.9	2
376	2.9	1.9	245	2.7	2.1	13	3.1	1.3	197	2.3	1.4	66	4.3	3.0	1,000	2.7	1.9	3
33	0.3	0.2	26	0.3	0.2	1	0.2	0.1	14	0.1	0.1	5	0.3	0.2	86	0.2	0.2	4
9	0.1		24	0.3	0.2				5			12	0.8	0.5	58	0.2	0.1	5
680	5.2	3.4	699	7.6	6.1	15	3.7	1.5	483	5.4	3.7	144	9.4	6.5	2,477	6.7	4.7	6
672	5.1	3.4	690	7.5	6.0	13	3.1	1.3	479	5.4	3.7	141	9.2	6.4	2,448	6.6	4.6	7
8	0.1		9	0.1	0.1	2	0.5	0.2	4			3	0.2	0.1	29	0.1	0.1	8
22	0.2	0.1	63	0.7	0.6	2	0.5	0.2	42	0.5	0.3	18	1.2	0.8	250	0.7	0.5	9
,004	100.0	65.4	9,222	100.0	80.6	420	100.0	41.7	8,915	100.0	67.4	1,528	100.0	69.8	36,969	100.0	70.3	10
,572	94.9	7.8	333	92.0	3.0	343	95.0	34.0	1,356	94.1	10.3	234	84.1	10.7	4,109	93.1	7.8	11
,521	91.7	7.6	322	88.9	2.9	332	91.9	32.9	1,309	90.9	10.0	218	78.4	10.0	3963	89.8	7.6	12
49	3.0	0.2	10	2.8	0.1	10	2.8	1.0	38	2.6	0.3	12	4.3	0.5	128	2.9	0.2	13
1	0.1						1.3	0.1	6	0.4		2	0.7	0.1	11	0.2		14
1	0.1		1	0.3					3	0.2		2	0.7	0.1	7	0.2		15
75	4.5	0.4	25	6.9	0.2	15	4.2	1.5	79	5.5	0.6	31	11.2	1.4	264	6.0	0.5	16
73	4.4	0.4	24	6.6	0.2	15	4.2	1.5	75	5.2	0.6	31	11.2	1.4	256	5.8	0.5	17
2	0.1		1	0.3					4	0.3					8	0.2		18
10	0.6	0.1	4	1.1		3	0.8	0.3	6	0.4		13	4.7	0.6	40	0.9	0.1	16
,657	100.0	8.3	362	100.0	3.2	361	100.0	35.8	1,441	100.0	10.9	278	100.0	12.7	4,413	100.0	8.4	20
457		2.3	206		1.8	33		3.3	240		1.8	91		4.2	1,304		2.5	21
149		0.7	119		1.0	23		2.3	174		1.3	9		0.4	498		0.9	22
,950		14.8	862		7.6	97		9.6	1,299		9.9	189		8.7	5,651		10.8	23
,124		5.7	517		4.5	52		5.2	879		6.7	55		2.5	2,683		5.1	24
511		2.6	140		1.2	18		1.8	245		1.8	33		1.5	967		1.8	25
,191		26.1	1,844		16.1	223		22.2	2,837		21.5	377		17.3	11,103		21.1	26
39		0.2	15		0.1	3		0.3	33		0.2	4		0.2	104		0.2	27
),891		100.0	11,443		100.0	1,007		100.0	13,226		100.0	2,187		100.0	52,589		100.0	28

Graduate study in engineering does not appear to be of any considerable consequence as a prerequisite to practice in engineering. (This fact was also brought out in the studies made by The American Society of Mechanical Engineers in its survey of the 1930 earnings of mechanical engineers.)

As the figures show, of the 52,589 engineers reporting, only 4,413, or 8.4 per cent, were graduates in engineering who were practicing in another branch of the profession than the one for which they had qualified in college. "Hence," Mr. Fraser observes, "considering the fact that some transfers in professional work are inevitable and that these are concentrated in but few professional classes, it can only be concluded that this tendency is an insignificant factor. . . . In other words, it may be concluded that by and large the respective curricula (of engineering colleges) meet the needs of the profession."

Other Engineers

From a section of Mr. Fraser's article dealing with "other engineers," the following excerpts are quoted:

In the group of "other engineers," 1,304, or 2.5 per cent of the nonengineering graduates reporting, had degrees in the liberal arts. This is not a very large proportion but it is interesting to note that this group has remained fairly constant since as far back as 1889. It is difficult to explain how such a group is able to attain professional status without formal education in the engineering field, although this is possible in some instances, such as chemical, ceramic, mining, and metallurgical, and architectural engineering. Nevertheless, it can safely be concluded that since graduates of academic courses have been in engineering fields over a long period, the probability is that they will continue to remain a factor in the profession.

Only 498 (0.9 per cent of the grand total) engineering graduates were reported as with further study in nonengineering fields. These persons had originally graduated in engineering, but later they swung into other fields of study, such as economics, business administration, law, etc. The small number found in this class is a substantiation of the fact that there is little transfer of occupation not only within the profession but also to preparation for professional work in fields other than engineering.

Engineering educators have for many years been aware that the "mortality" (i. e., the proportion dropping out before completion of course) among engineering students is very high, this having been disclosed by many previous studies. The number covered by the present survey who reported that they did not finish the engineering course in college was 5,651, or 10.8 per cent of the total.

Noncollegiate technical-school engineers numbered 2,683 or 5.1 per cent of the grand total reporting.

Of 967 engineers reported as having only a secondary-school education, the largest numbers were civil and mechanical engineers, the total of these being 756, or 78.2 per cent of the 867 reporting.

In order to determine more clearly the nature of the general trends with regard to the "other engineers" group, an analysis of the distribution as between all graduates and the nongraduates of the "other engineers" is necessary. Of the engineers classified as "recent" since they entered the profession after the 1930 census, 18,451, or 98.48 per cent, reported as having graduated between 1930 and 1934. Contrasted to this group, there are only 286, or 1.52 per cent, "other engineers," i. e., those who did not report graduation but were born within the period of 1910–15. On the other hand, there are 33,852 older engineers, of whom 24,837, or 73.4 per cent, reported graduation up to and including 1929. This may be compared, however, with 9,015 "other engineers" (26.57 per cent) who did not report graduation but were born within the period ending with 1909. The enormous decrease in the ratio of

Table III—Distribution of Nongraduates Among "Other Engineers," by Year of Birth, in the United States, 1934

Education	Born in Period	Total Number	Total Per Cent	Professional Class: Agricultural	Architectural	Ceramic	Chemical	Civil	Electrical	Industrial	Mechanical	Mining and Metallurgical
Nongraduate engineers:												
1. College engineering course unfinished	1910–14	218	3.9		2	1	15	94	49	5	39	13
	1905–09	738	13.1		12	4	32	352	153	16	150	19
	1900–04	914	16.2	3	9	3	21	443	198	13	211	13
	1895–99	899	15.9	3	6	3	22	435	157	29	215	29
	1890–94	790	14.0	7	13	2	17	412	101	13	202	23
	1885–89	790	14.0	1	13	3	16	450	88	11	176	32
	1880–84	596	10.5	3	5		14	341	57	6	144	26
	1875–79	348	6.1		2		7	212	34	2	76	15
	1874[a]	358	6.3		5		10	211	25	2	86	19
Total		5,651	100.0	17	67	16	154	2,950	862	97	1,299	189
2. Noncollegiate technical school	1910–14	52	1.9				1	14	22		13	2
	1905–09	224	8.3		2	2	2	88	84	3	43	
	1900–04	360	13.4		3		3	144	99	8	100	3
	1895–99	375	14.0	1	3	1	2	156	84	7	113	8
	1890–94	476	17.8	1	4		6	201	68	14	175	7
	1885–89	452	16.8	1	6		3	186	70	6	169	11
	1880–84	358	13.4		4		1	169	49	8	119	8
	1875–79	199	7.4	1	1	2	2	84	28	6	72	3
	1874[a]	187	7.0	1	3			82	13		75	13
Total		2,683	100.0	5	26	5	20	1,124	517	52	879	55
3. Secondary school	1910–14	16	1.7			1		5	7		2	1
	1905–09	88	9.1				2	49	25		12	
	1900–04	110	11.4	1			1	57	24		25	2
	1895–99	128	13.2			4		58	21	3	36	6
	1890–94	152	15.7	2	1			78	17	4	45	5
	1885–89	165	17.1	3	2			86	19	7	43	5
	1880–84	108	11.1					56	13	1	35	3
	1875–79	83	8.6					50	8	1	20	4
	1874[a]	117	12.1		3			72	6	2	27	7
Total		967	100.0	6	6	5	3	511	140	18	245	33
Total nongraduate engineers		9,301	17.7	28	99	26	177	4,585	1,519	167	2,423	277
Graduate engineers		43,288	82.3	369	439	362	3,335	15,306	9,924	840	10,803	1,910
Grand total		52,589	100.0	397	538	388	3,512	19,891	11,443	1,007	13,226	2,187

[a] Or earlier.

"other engineers" to graduates as between the older and recent engineers is the best evidence that graduation in engineering is almost a necessity for entry into the profession.

The demand for graduation as a qualification for professional status in engineering is not a recent development; it is a growing trend that may be traced back for more than 50 years. This is clearly brought out in table III, which presents data for the 3 classes of nongraduates of the "other engineers," showing in each case their distribution by year of birth as of 1934. . . . The small percentage of recent engineers, compared to the large percentage of old engineers, in each of these 3 groups of nongraduates again emphasizes the fact that the chances of attaining professional status without a college degree have markedly decreased.

Fields and Functions

Table IV shows an analysis of the fields of activity and the functional classification of engineers. Mr. Fraser says, "only those engineers who had an engineering job as of December 31, 1934, were interrogated on these points, this explains the 2 totals in table IV, given as 'reporting' and 'not reporting' the field of activity and functional classification in the nine professional classes." He continues:

Strictly speaking, the fields of activity and functional classifications may more simply be described as the branches of engineering engaged in and the functions performed in those branches. With respect to the field of activity, this is quite obvious in some instances, such as mining and metallurgical engineering.

Of the agricultural engineers reported as employed on December 31, 1934, no less than 51.5 per cent were in Government work, probably due to the great demand for engineers in such work as soil erosion, irrigation, etc. Personal service absorbed 27.7 per cent of the total, the remaining agricultural engineers being distributed in construction, manufacturing, public utilities, and private utilities, and private agriculture and forestry. . . . .

The architectural engineers also found Government work the best recent possibility for employment, with 40.3 per cent so employed; 39.4 per cent were in private construction, and only 10 per cent in manufacturing, the remainder being in public utilities, personal service, and extractive industries. . . . .

Ceramic and chemical engineers are very similar with regard to their distributions in both the fields of activity and functional classifications. In each case, the largest percentage is to be noted in manufacturing, the figures being 86.8 for ceramic and 72 for chemical engineering. The number engaged in Government work formed only 6.7 per cent of the chemical and 2.6 per cent of the ceramic engineers. . . . .

Referring to civil engineers, the percentage of those employed by Governmental agencies is no less than 63.3, the next highest being those in private organizations rendering engineering service, with only 15.4 per cent. This unusually large relative number in Government work is explained primarily by the almost complete cessation, during the period immediately preceding the survey, of civil engineering opportunities in the normal fields of activity other than Government. In the distribution of the civil engineers with regard to functional classifications, construction leads with 45.7 per cent, followed by design and research with 21.8 per cent, and operation with 12.5 per cent—a total of 90 per cent in these three classifications.

As anticipated, the percentage of electrical engineers in public utilities is high, being 39.7, but it is also interesting to note that as many as 33.7 per cent reported manufacturing as their field of activity. No less than 9.8 per cent were in Government work, and 9.1 per cent were in personal service. Again (as for civil engineers) the first 3 functional classifications cover 72 per cent of all reporting, although the order is operation with 34.1 per cent, design, and research with 27.9 per cent and construction with 10.8 per cent.

Industrial and mechanical engineers are largely in manufacturing, the former having 66.8 per cent and the latter 52.2 per cent of the

total. In the case of industrial engineers, the next highest percentages were 8.8 in public utilities and 8.1 in personal service, and for mechanical engineers 9.9 in personal service, 8.7 in construction, and 8.4 in public utilities. With reference to the distribution, by functional classification, of the 682 industrial engineers reporting, 33.6 per cent were in operation, 27.4 per cent were in general administration and management, and 13.5 per cent were in design and research. Of the 8,764 mechanical engineers, the highest percentage 33.8, was in design and research, while 25.9 per cent were in operation, 9.6 in construction, and 8.8 in administration and management.

Naturally, the highest percentage of mining and metallurgical engineers is in extractive industries, where 47.3 per cent were employed, although it is interesting to note that no less than 27.7 per cent reported manufacturing as their field of activity. The next 2 highest were 11 per cent each for personal service and Government work. As for the distribution by functional classification, the highest percentage appears in operation with 43.4, followed by design and research with 19.4. However, it will be seen that there is some importance attached to consulting as far as this professional class is concerned, as 11.2 per cent report this as their functional classification.

When all the engineers reporting the field of activity are considered, the order of distribution is as follows: 30.4 per cent in manufacturing, 31.5 per cent in Government work, 11.8 per cent in public utilities, 9.6 per cent in construction, 8.1 per cent in personal services, and 5.1 per cent in extractive industries. For functional classification, design and research is first with 26.6 per cent, operation with 24.2 per cent, construction with 24.1 per cent, general administration and management with 8.3 per cent, consulting with 6.4 per cent, teaching with 5.9 per cent, and sales with 4.5 per cent.

The import of this analysis is that there are certain well-defined fields of activity for each of the professional classes. In the case of agricultural and civil engineers it is obviously Government work. Architectural engineers are fairly well divided between construction and Government work; ceramic, chemical, industrial, and mechanical engineers are largely concentrated in manufacturing; electrical engineers are found mostly in public utilities and manufacturing; and mining and metallurgical engineers appear mostly in the extractive, industrial, and manufacturing zones. For each of the professional classes the outstanding functional classification are design and research, construction, and operation.

Table IV—Distribution of Engineers by Zones of Interest and Functional Classifications, in the United States, 1934

	Professional Classes									
	Agricultural		Architectural		Ceramic		Chemical		Civil	
Classification	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent
Field of Activity										
Construction	29	9.4	91	39.4	5	1.9	32	1.4	2,148	15.4
Extractive industries			2	0.9	8	3.0	147	6.7	447	3.2
Public utilities	13	4.3	11	4.7	1	0.4	104	4.7	484	3.5
Transportation							18	0.8	517	3.7
Manufacturing	21	6.8	23	10.0	231	86.8	1,592	72.0	705	5.1
Personal service	85	27.7	11	4.7	14	5.3	171	7.7	808	5.8
Agriculture and forestry	1	0.3								
Government work[1]	158	51.5	93	40.3	7	2.6	148	6.7	8,812	63.3
Total	307	100.0	231	100.0	266	100.0	2,212	100.0	13,921	100.0
Total not reporting	90		307		122		1,300		5,970	
Functional Classification										
Design and research	69	22.5	72	31.2	77	28.9	727	32.9	3,030	21.8
Construction	85	27.7	102	44.1	9	3.4	48	2.1	6,368	45.7
Operation	22	7.1	13	5.7	138	51.9	1,051	47.5	1,741	12.5
Consulting[2]	34	11.1	17	7.3	8	3.0	95	4.3	874	6.3
Teaching	62	20.2	9	3.9	11	4.2	128	5.8	553	4.0
Sales	12	3.9	7	3.0	8	3.0	67	3.1	175	1.2
General administration and management	23	7.5	11	4.8	15	5.6	96	4.3	1,180	8.5
Total	307	100.0	231	100.0	266	100.0	2,212	100.0	13,921	100.0
Total not reporting	90		307		122		1,300		5,970	

	Professional Classes									
	Electrical		Industrial		Mechanical		Mining and Metal		Total	
Classification	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent	Number	Per Cent
Field of Activity										
Construction	184	2.8	35	5.1	762	8.7	22	1.5	3,308	9.6
Extractive industries	126	1.9	25	3.7	328	3.7	684	47.3	1,767	5.1
Public utilities	2,634	39.7	60	8.8	734	8.4	19	1.3	4,060	11.8
Transportation	199	3.0	19	2.8	429	4.9	4	0.2	1,186	3.5
Manufacturing	2,231	33.7	456	66.8	4,841	55.2	399	27.7	10,499	30.4
Personal service	602	9.1	55	8.1	866	9.9	160	11.0	2,772	8.1
Agriculture and forestry					1	(3)			2	(3)
Government work[1]	650	9.8	32	4.7	803	9.2	160	11.0	10,863	31.5
Total	6,626	100.0	682	100.0	8,764	100.0	1,448	100.0	34,457	100.0
Total not reporting	4,817		325		4,462		739		18,132	
Functional classification										
Design and research	1,846	27.9	92	13.5	2,960	33.8	281	19.4	9,154	26.6
Construction	717	10.8	42	6.1	841	9.6	97	6.7	8,309	24.1
Operation	2,261	34.1	229	33.6	2,271	25.9	629	43.4	8,355	24.2
Consulting[2]	423	6.4	67	9.8	507	5.8	161	11.2	2,186	6.4
Teaching	487	7.3	24	3.6	635	7.2	127	8.7	2,036	5.9
Sales	434	6.6	41	6.0	777	8.9	28	2.0	1,549	4.5
General administration and management	458	6.9	187	27.4	773	8.8	125	8.6	2,868	8.3
Total	6,626	100.0	682	100.0	8,764	100.0	1,448	100.0	34,457	100.0
Total not reporting	4,817		325		4,462		739		18,132	

[1] Includes federal, state, county, and municipal.
[2] Includes independent consultants and employees of consulting firms.
[3] Less than 1/10 of 1 per cent.

The Resistance Welding Circuit

This paper treats in something of an elementary fashion some of the problems encountered in the practical application of the resistance welding circuit, considering especially the electrical constants and variables involved. The lack of available literature on this subject inspired the preparation of this paper.

By
C. L. PFEIFFER
MEMBER A.I.E.E.

Western Electric Co.
Chicago, Ill.

MANY are familiar with spot welding and other resistance welding machines, but only a few other than welding engineers realize how important is the co-ordination of the 3 principal factors: current, electrode pressure, and time of current application. For a given condition these factors may be determined and a perfect joint made. The welding machine can duplicate these conditions time after time if no change creeps in in the form of material changes, electrode contact, or electrode wear variation.

To reproduce similar pressure conditions uniformly for each welded joint presents less difficulty than any of the other factors. Electrode pressure usually is applied directly by means of air cylinders, springs, cams, or combinations of these. There is little chance of change in successive operating cycles if proper clearances and lubrication are provided for these mechanisms or associated parts such as electrodes. Of course, variations in thickness of material may affect pressure conditions unless compensated for. If materials are being welded on which either constant or other critical unvarying pressure adjustments are necessary the use of either longer springs in combination with a cam having little variation in pressure in advancing or receding very small distances, or the use of a combination of springs, will give good results. If air is suitable, the resultant pressure also may be held quite constant.

At present the demands for an exact interval of time are much more severe than they were a few years ago. When current is applied for periods of from 1 to 10 seconds, variations of 0.1 second mean only a difference of from 1 to 10 per cent in total time. These time intervals are not acceptable for many production requirements, and it is not uncommon at present to work in periods of 0.1 second or less, where a variation of 0.1 second may mean a difference of 100 per cent or more in power supplied. Contactors of the magnetic type used for closing and interrupting current supply, in fact nearly all mechanical devices, are satisfactory for all except very short intervals of time; these require some type of vacuum tube control that gives exact time intervals of a number of half-cycle periods of alternating current supply. It is only this recent development of an exact timing interval that has made possible the development of satisfactory production processes for resistance welding such materials as high-heat or electrically conductive metals, and also alloys highly susceptible to certain critical temperatures.

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Although seemingly simple at first thought, the great problem for improvement in resistance welding processes is absolute control of power input to the weld area. For example, consider the conditions met with in making a simple spot weld. In figure 1 are shown 2 sheets of material, M_1 and M_2 between electrodes E_1 and E_2, the latter connected through large copper conductors to the secondary of the welding transformer. The current flowing through the weld area follows the law

$$I = \frac{E}{Z}$$

where

I = total current flowing
E = induced voltage in secondary of transformer
Z = total impedance of the weld circuit including the transformer resistance and reactance

For a given primary tap the induced voltage in the secondary is approximately constant, the voltage dropping only as the load increases. The impedance of that part of the circuit from electrode to electrode through the transformer also may be assumed to be constant for a given material and type of weld. The several contact resistances in that part of the circuit from electrode to electrode through the weld material introduce possible variables into the weld circuit, and difficulties that occur from time to time often are traced to this source.

These contact resistances are caused principally by oxide formations on the surfaces of the materials, and vary according to electrode pressure values. Therefore, the usable electrode pressures fall between certain limiting values, below which contact resistance becomes too large or too unstable for suitable welding operations, and above which the material collapses before reaching a suitable temperature for fusion. Oxide formations, dirt, grease, or other poor surface conditions should be eliminated as far

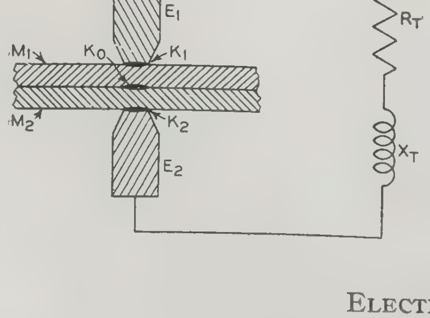


Fig. 1. A simple welding circuit

as possible, either by suitable chemical washing or by purely mechanical means.

In most other electrical circuits the voltage values are high enough and current values low enough to cause little concern over contact resistances of the order of 0.0001 ohm, but in resistance welding, where the induced secondary transformer voltage may only be 2, 3, or 6 volts and the total circuit impedance only 0.001 ohm or less, such values assume tremendous importance. Of course some resistance is desirable in the contact or junction between the materials being welded because this resistance localizes the heat energy at the correct place of weld application according to the law I^2R. Contact resistances at the electrode surfaces, however, are undesirable and should be reduced as much as possible.

When the spot welding current is applied to 2 sheets as shown in figure 1 the result is a simple series circuit with total current the same in each part. The current density is low in that part of the circuit marked $E_1R_1X_1R_TX_TE_2$ because this part consisting of electrodes, transformer leads, and transformer loop is made of sufficient cross section to withstand heavy currents without undue heating. At the electrode tips where the current enters sheets M_1 and M_2 the current is restricted to the electrode contact area, and this, no doubt, is the area of greatest current density. The current density in and between the sheets is lower than at the electrodes because the path is less restricted after leaving the electrode faces, and the effective contact area between sheets is much smaller than popularly believed. In fact, it generally can be assumed that this area is approximately equivalent to the average of the 2 electrode contact areas except for the case of thin sheets where one electrode has a large surface area to prevent discoloration while the heat in the weld area is localized by the other electrode contact surface. When sheets are placed together for welding, the general contact is poor and it is only when placed between electrodes under pressure that a somewhat reliable contact is made. When current is sent through the electrode area, the heat of expansion tends to force the sheets apart as shown in exaggerated form in figure 2. With this condition existing and a knowledge of other factors effecting resistance welding, it seems convenient to assume that an equivalent resistance value between electrodes for thin sheets is approximately 3 times that of a column of material of cross section the same as

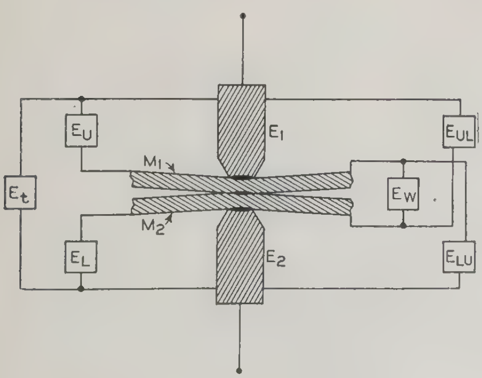
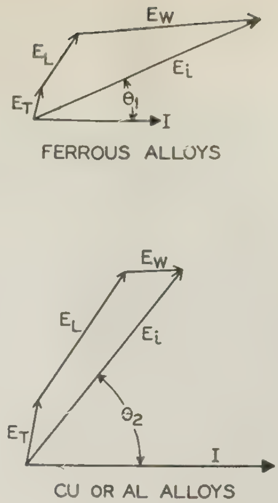


Fig. 2. Diagrammatic indication of tendency of heat expansion to force sheets apart

Fig. 3. Typical vector diagrams showing extremes in spot welding circuits. Per cent values of voltage and current tabulated



	FE	CU
E_i	1.00	1.00
E_T	0.14	0.27
E_L	0.26	0.60
E_W	0.75	0.20
I	0.50	1.00
$\cos\theta_1$	0.9	
$\cos\theta_2$		0.6

the electrode surface. This factor of 3 should be given further explanation and it should be understood that it is an approximation which has been more or less useful in predicting, or rather picturing, the voltage drop in the weld area. It is of interest to follow a discussion on pages 350–53 of Jeans' "The Mathematical Theory of Electricity and Magnetism" and also to follow some crude attempts at measurement of voltage drops in the weld area.

Jeans discusses the current flow in a conductor of infinite cross section, and, for the special case of large sheets placed between 2 electrodes as is done in spot welding such a condition is simulated. The area in a sheet of material is divided into 3 sections of resistance: (1) a resistance at the crossing of the current from the restricted area of contact of the electrode to the medium; (2) the medium itself; and (3) the crossing of current from the medium to the other restricted area which contacts the electrode. Further, inasmuch as the medium has infinite cross section—and in most practical cases sheets being welded can be thought of as having infinite cross section—this area is considered negligible or of zero resistance. This leaves the other 2 sections, each one of which is called "the resistance of a single junction between an electrode and the conducting medium surrounding it." Jeans also discusses these resistances in connection with a circular plate or disk similar to the surface of a spot welding electrode, and gives the resistance of the junction as equal to $\frac{\tau}{4a}$ where τ is the specific resistance of the medium and a the radius of the disk or electrode surface. This area, called "the crossing of current from the medium to the electrode," must not be confused with contact resistance between the electrodes and the parts being welded, but must be pictured as a separate area where the current spreads out from the restrictive cross section of the electrode surface which contacts the medium to the medium itself. It would follow from this that for different thicknesses of sheet the resistance of the material remains the same but for different electrode areas the resistance is inversely proportional to the radius of the contacting surface. This appears quite logical for a spot welding circuit, for it is known from ex-

perience that the required currents for making a weld depend principally upon the impedance of the transformer and leads and very little upon the impedance of weld area.

Upon many occasions voltage, current, and pressure measurements have been made on copper, brass, iron, or bronze sheets of thickness from 0.010 to 0.0625 inch between electrode surfaces of from $^1/_{16}$ to $^1/_8$ inch in diameter, and many of these measurements check approximately with predicted values. The points at which these measurements have been taken are indicated in figure 2. Assume 2 pieces of 0.022 inch phosphor bronze between electrodes having a surface diameter of 0.062 inch (0.156 centimeter) and under a pressure of 9 pounds. Average measurements on numerous samples under the same circuit conditions may be approximately:

Total voltage across weld area..........	$= E_t =$	0.45 volt
Voltage across weld....................	$= E_W =$	0.13 volt
Open circuit voltage of secondary loop...	$= E_0 =$	1.35 volts
Induced voltage in secondary under load measured with exploring loop of wire parallel to secondary loop............	$= E_{EC} =$	1.16 volts
Voltage between upper electrode and upper sheet.........................	$= E_U =$	0.16 volt
Voltage between lower electrode and lower sheet............................	$= E_L =$	0.17 volt
Voltage between upper electrode and lower sheet.........................	$= E_{UL} =$	0.22 volt
Voltage between lower electrode and upper sheet.........................	$= E_{LU} =$	0.22 volt
Primary voltage.........................	$= E_P =$	440 volts
Primary current.........................	$= I_P =$	10 amperes

and it is remarkable how often successive readings are identical. From these data may be calculated a secondary current of about 2,700 amperes. The mil-foot resistance of phosphor bronze is about 40 at zero degrees centigrade, and it is estimated at about 80 for welding temperatures. Thus a column 0.044 inch long 0.062 inch in diameter has a resistance of

$$\frac{44(80)}{12(1000)(62)^2} = 0.0000762 \text{ ohm}$$

and the voltage drop between electrodes is

$$0.0000762 \times 2700 = 0.20574 \text{ volt}$$

If this is multiplied by the factor 3, a total of 0.61 volt should be read across the weld area. Although this is considerably greater than the measured voltage of 0.45, it still is reasonably close and many measurements have been made which, for a group of readings, have been just as close.

If Jeans' formula of $R = \frac{\tau}{4a}$ is followed for the same

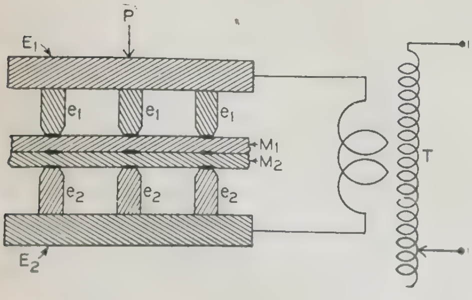


Fig. 4. Conventional circuits for multiple spot welding

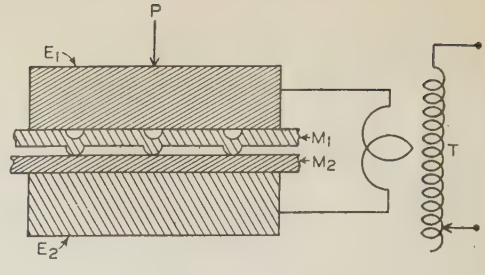


Fig. 5. Projection method of spot welding

example using electrodes of 0.062 inch (0.156 centimeter) in diameter, a value of 6.8 microhms (40 ohms per mil foot) for the phosphor bronze,

$$R = \frac{6.8}{4(0.078)} = 21.4 \text{ microhms or } 0.0000214 \text{ ohm}$$

There are at the beginning of the welding operation at least 4 junction areas, hence that the total drop is

$$4(0.0000214)2700 = 0.23112 \text{ volt}$$

This voltage plus the IR drop of contact resistance should check with the measured voltage of 0.45 across the weld area. However, it is difficult to decide what value of T to use in the formula. At the instant the weld starts and before any heating takes place the value 6.8 for specific resistance 6.8 is correct, but at the completion of the weld, the increase in temperature has approximately doubled this figure. At the same time the 2 junction areas of resistance at the weld proper between the sheets disappeared or at least changed greatly.

The foregoing discussion is in a field of approximations, and subject to large possible errors in measurements or other assumptions, but the subject matter is interesting and leads one to believe that the factor dealing with current restrictions introduced into the weld area by the design of parts being welded and by electrode contact areas is as important as the factors involving contact resistance and thermal conductivity.

Although even small variations in contact resistance are undesirable, they cannot be entirely eliminated. However, means may be employed to stabilize the current to some extent. The case which often presents itself is the resistance which breaks down after a specific time interval of applied voltage and current. If a very slow weld on 2 sheets of iron is made with a voltage low enough, one may observe at first practically open circuit voltage across the material; after 4 or 5 seconds this voltage drops to half that value, and then after another second or less the weld will be complete. By using 6 or 7 sheets of material this condition may be magnified greatly; in fact it may never break down. For iron there is also the magnetic effect which retards current flow and which is partially eliminated when a definite temperature is reached. However, the contact resistance effect, which breaks down during the welding cycle, is present for all metals, and most likely is one of the principal causes of difficulty in welding some of the nonferrous metals such as brass. When insufficient heat results in a failure to weld, it is natural to increase the welding voltage to cause more current flow, and it is annoying to find that this increase in voltage causes the resistance to break

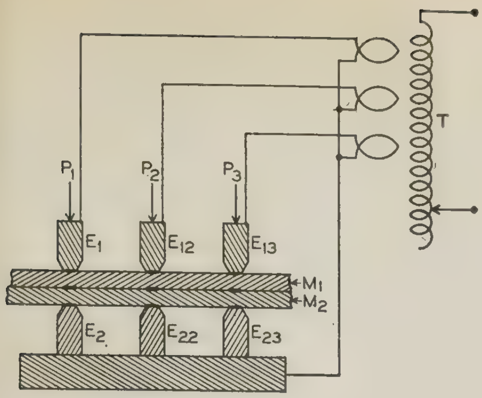


Fig. 6. Circuit variation to overcome difficulties encountered in circuit of figure 4

down whereupon too much current flows. This condition usually is remedied by reducing the efficiency of the welding circuit by introducing ballast resistance and reactance. This allows a higher breakdown voltage to be used and also limits the current to definite values to prevent burning of parts. If very short intervals of time such as 2 or 3 cycles of 60 cycle supply are used, the resistance breakdown requirements of voltage are less important because the voltages required for the high currents of short time intervals often are above the breakdown voltage requirements of many materials.

In highly efficient circuits the characteristics of the material being welded affect the current flow to a much greater degree than in relatively inefficient circuits. For example, with iron or steel the voltage drop across the material being welded may amount to from 50 to 80 per cent of the total drop in the circuit. If copper, brass, or aluminum is substituted the voltage drop across the material may only be from 10 to 40 per cent, but the current may be 400 or 500 per cent greater. The total energy input to the weld for the same settings for these different materials may remain approximately the same and in each case could make a satisfactory weld. However, the introduction of a surface condition either on material or electrodes has a much greater effect on the material of low resistivity in that the current is reduced enough to prevent a satisfactory welded joint being made. However, the effect of a surface condition of the same impedance value for iron or steel may hardly be noticeable in the quality of joint. It is this condition that makes difficult the welding of materials of high electrical conductivity such as copper, brass, or aluminum, because surface conditions often force the use of currents higher than otherwise necessary with the result that the joint is badly burned when the surface resistance between parts or between electrodes and parts approaches zero.

The positive resistance characteristics of metals being welded, wherein an increase in current and temperature increases the resistance, offer no particular difficulty not easily compensated for by machine adjustment, but the negative resistance characteristics of most oxides or other foreign matter introduced between sheets or between electrode tips and sheets gives much trouble. A relatively high breakdown voltage is required to start the current flow, necessitating the use of a power cut-off device to prevent the joint from being burned up, once the current flow does start. Increase or decrease of current is of little importance unless the variation in succeeding operations is great; because oxide conditions present such a variable, they are undesirable. The use of high current densities, the use of relatively high voltages and short intervals of time are the best weapons with which to combat these variables. The high voltage nullifies the initial current-blocking effect of most oxides, while the high current density with its associated short interval of time and mechanical movements of electrodes completes the heating cycle, in spite of possible slight current variables, before the heat can dissipate to adjoining sections or an arc can form to burn out any metal.

Considering the importance of resistance welding, it is surprising that so little has been written about the electrical constants and variables in this circuit. Usually it is a simple series circuit, and theoretically presents no difficulties of analysis. In the matter of actual measurement the circuit differs because very high currents and correspondingly low voltages are involved. A typical example would be a current of 20,000 amperes, a voltage of 6, and several separate reactances and resistances totaling some 0.0003 ohm. It is difficult to measure impedance values of the order of 0.00001 ohm, and this may account for the fact that little engineering effort has been expended on this circuit.

Typical vector diagrams showing extremes in spot welding circuits are shown in figure 3, the upper and lower diagrams respectively showing the voltage distribution for high resistance ferrous alloys and for low resistance copper or aluminum alloys. E_i, E_W, E_L, E_T represent total induced voltage, and voltage drops in the weld area, the leads, and in the transformer respectively, I is the current vector, and θ the power factor angle. For ferrous alloys the voltage drop across the weld is approximately 75 per cent of the numerical value of induced voltage; for the high conductivity alloys it is approximately 20 per cent, and for the same value of induced voltage the current is shown doubled for the metals of high conductivity. The diagrams also emphasize the limitations of power factor, for these 2 types of weld, in that neither one can be raised without making the circuit more inefficient. These diagrams have been drawn to scale and the per cent values of current and voltage used shown at the right.

The values shown are averages resulting from many

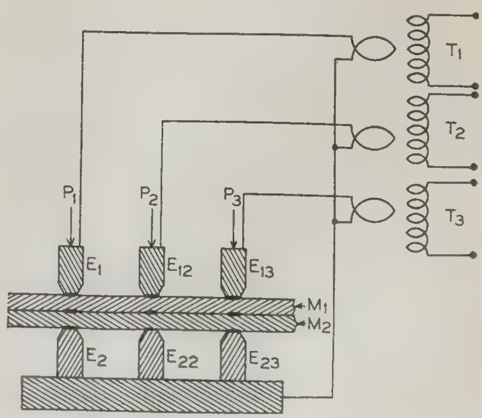


Fig. 7. A variation of circuits shown in figure 6

readings taken in connection with special problems, and represent oscillographic as well as direct readings made with low reading voltmeters. E_i was measured by inserting a copper strip exploring coil next to and parallel to the secondary loop, and measuring its terminal voltage during a weld period. E_L and E_W may be measured directly and E_T was obtained by substracting vectorially E_L and E_W from E_i. The angle between the induced voltage and current is an approximation arrived at from the primary circuit wattmeter, voltage, and current readings and corrected for a relatively large magnetizing current. It may be of interest to state that low reading voltmeters (0–1 scale) take fairly accurate readings in a time of 1 second if a stop is placed behind the pointer to eliminate the swing from the zero position. Also, to give sufficient time to read, the electrode surface area is increased sufficiently to prevent the weld from burning up during the longer time period. By comparing current values of actual welds and the joints made by increasing the electrode area one gets an idea of possible error, but in most cases very little difference is noted in weld current. For low carbon steels it is quite simple to make satisfactory welds in from 1 to 2 seconds of reading period; good butt-welds in large copper rod also can be made in periods of from 3/4 to 1 second.

The foregoing provides an excellent background for the discussion of multiple welding circuits as used in both spot and projection welding. The 4 diagrams (figures 4 to 7) indicate elements in circuit design for making 2 or more spot welds at one time. As many as 50 or more spots may be made by these or similar arrangements. In figure 4 is shown a conventional diagram of welding transformer and upper and lower electrodes E_1 and E_2 with 3 sets of subelectrodes e_1 and e_2 for making 3 spot welds simultaneously in material M_1 and M_2. The circuit from E_1 to E_2 through the welds consists of 3 paths; as long as the impedance in each path is identical each will heat at the same rate, and under common pressure conditions all will reach the proper welding temperature at the same time, and result in 3 perfect welds. However, if the resistance in each path is different because of variations in contact resistance the current will divide in the inverse ratio of the impedances, and if the differences are large enough some spots will burn because of excess current and others may not become hot, enough to make possible a joint of any kind.

To illustrate, assume an induced secondary voltage of 7.8 volts, a total transformer and lead reactance and resistance of 0.0003 ohm each, and a reactance and resistance of 0.0001 and 0.0003 ohm for each of the 3 parallel circuits e_1 to e_2. This will give a total of 15,000 amperes or 5,000 amperes through each weld. Now, consider this small value of 0.0003 ohm resistance for each weld area, and assume that because of variations in either electrode contact area surfaces, individual electrode pressure, material, or other associated condition in the locality between e_1 and e_2 the resistances of these 3 parallel circuits has changed from 0.0003 ohm each to 0.00015, 0.0003, and 0.0006 ohm, respectively, while the reactances remain the same. Also assume that, since the total current remains within about 2 per cent of its former value, the same secondary voltage is applied to the welding circuit. Under these conditions the current through each weld area, instead of being 5,000 amperes, is calculated at 7,960, 4,560, and 2,370 amperes, respectively. Welding of parts such as these usually is not very critical, but the chances are that although one joint will be satisfactory, another may be burned by an excess of current and the other a poor weld because of the low current. The exact energy input may be calculated by substituting values for I^2R, in which case the joint having the higher current has an increase of more than 20 per cent, while the joint having the lower current has a decrease of more than 50 per cent.

One of the remedies for this kind of trouble is the projection weld shown in figure 5, which, during the last ten years, has become very popular. In this type of weld the possibility of variation in electrode contact or area of contact has been greatly reduced and both the area of contact and quality of contact between surfaces being welded have been made more stable by the definite area of embossed contact and the higher pressures used.

Methods of greatly reducing the possible welding difficulties of figure 4 are shown in figures 6 and 7; respectively a separate secondary circuit for each electrode, and a separate transformer for each electrode, with a separate pressure mechanism for each electrode in each case. If in figure 7 the welds are made consecutively, that is, by synchronizing each application of current with successive electrode movements, only one transformer of relatively low capacity is necessary.

The ideal way to make perfect welds is to control the energy input to the weld area, which means control of current value through the weld, voltage drop across the weld, and time of current application. An integrating watt-hour meter which operates instantaneously, that is, within a half cycle of current supply in combination with vacuum tube grid controls might do this. Another means for weld control might be to apply to a grid circuit the vector summation of the normal voltages across the weld and across part of the secondary leads used as a current shunt, having the tube operate an indicator to record a normal weld.

Simple though the resistance welding circuit is, it does at times present some difficulties of operation, and these are closely linked with the co-ordination of very short intervals of time and very low voltages as applied to circuits of very low impedance in which contact resistances are apt to vary.

In connection with power supply, one may say that although all resistance welders of low kilovolt-ampere rating and even seam welders of higher rating as well as high speed spot welders are power loads easily absorbed in the power system, the development of projection welders of high kilovolt-ampere rating drawing an instantaneous primary load of 5,000 amperes at 440 volts or more for approximately $^1/_4$ second at intervals of from 10 to 50 seconds are a distinct power supply problem and usually require special accommodations. Separate power lines usually are necessary and, where a battery of welders

is being used, electrical interlocks are necessary to distribute the load properly.

In summing up the foregoing discussion one should bear in mind that the material presented is of an elementary nature and that it has been given for the purpose of bringing to the fore a subject about which little has been written. The spot welding circuit is not difficult to analyze in theory, but to appreciate its application and limitations more definite knowledge of values in the weld area is required. One should know the current and voltage drops required at the point of weld, just where the current flows, how the voltage drops are distributed and what factors affect the quality of joint. It is hoped that the material that has been presented in this article will stimulate a thorough investigation of this circuit especially that part of the circuit that lies in the weld area.

An Electronic Regulator for D-C Generators

A voltage regulator using grid-controlled arc-discharge tubes as rectifiers under the control of a diode to supply field current for d-c generators is described in this paper. The regulator has demonstrated an over-all sensitivity of plus or minus 0.5 per cent with a supply voltage change of 10 per cent, and is comparable in cost to the usual electromagnetic regulators, but requires an a-c supply.

By
F. H. GULLIKSEN
MEMBER A.I.E.E.

Westinghouse Elec. and Mfg. Co., East Pittsburgh, Pa

ELECTRONIC voltage regulators for d-c generators have been available commercially during the past 4 years, and have proved useful in applications where extremely close regulation has been needed. These regulators, which have a sensitivity of $\pm$ 0.1 per cent, are too expensive for many industrial applications, for which the less expensive electromagnetic type of regulator gives satisfactory operation.

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The regulator described in this paper, and shown in figure 1, forms the next logical step in electronic regulator design, namely, a regulator that can compete with some of the conventional electromagnetic regulators on a price basis, is more sensitive, and has faster response characteristics.

Principle of Operation

As may be seen from the schematic diagram in figure 2, the control circuits are extremely simple and the regulator consists of few component parts. Fundamentally the regulator is a grid-controlled full-wave rectifier, consisting of tubes T_1 and T_2, supplying rectified current to the generator field. The grid control is obtained through the action of the diode T_3 whose anode current is a function of the generator armature voltage. The characteristic of diode T_3 is such that the current between the anode and the cathode is primarily a function of the cathode temperature and therefore a function of the cathode current as shown in figure 3, which gives the voltage drop across resistor R_1 as the cathode current is varied, with the assumption of a constant 125 volt d-c supply. If the resistance in series with the cathode be kept constant and the voltage of the d-c supply be varied the curve in figure 4 results. This curve represents the voltage E_1 between A and B. When E is of high value, A is negative in relation to B; but as E is lowered the relative polarity of A and B is reversed. As shown in figure 2, B is connected to the cathodes of tubes T_1 and T_2 and A is connected to the common terminal of R_2 and R_3. The grid to cathode voltages of tubes T_1 and T_2 are, therefore, composed of the continuous voltage E_1 between A and B and the voltage drops across R_2 and R_3, each equaling half of voltage E_2, which by means of phase shift circuit CR_4 is caused to lag the anode supply voltage E_3.

In figure 5 is shown the variation of current through tubes T_1 and T_2, i. e., generator field current,

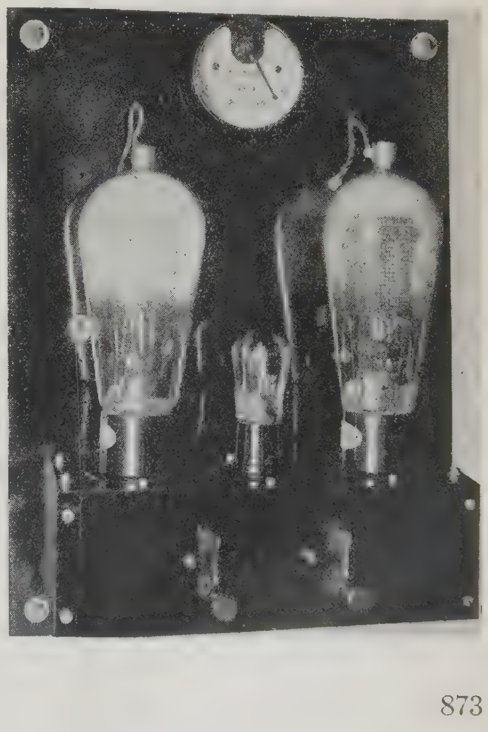


Fig. 1. Electronic voltage regulator

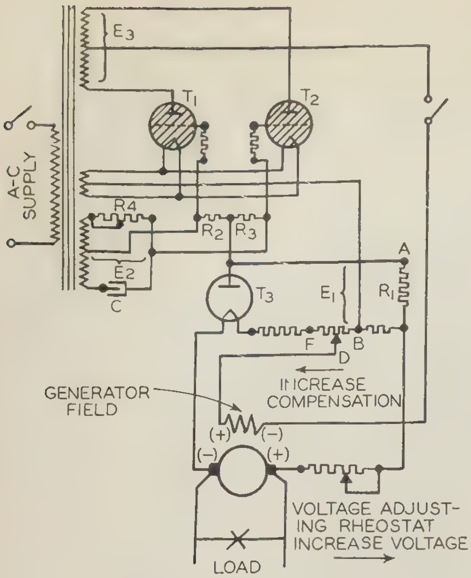


Fig. 2. Schematic diagram of electronic voltage regulator

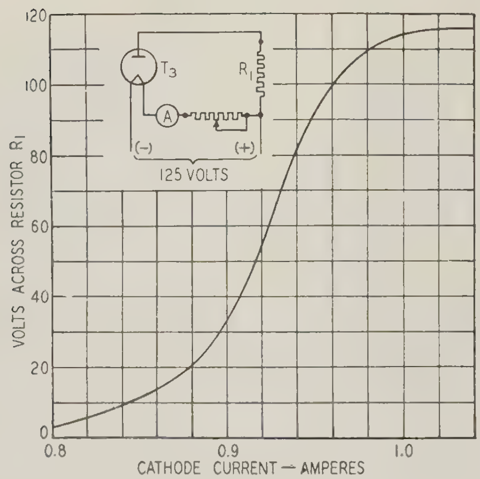


Fig. 3. Characteristic curve for diode

as the continuous voltage E_1 is varied. When E_1 is made more positive, the point on the voltage wave E_3 at which the tubes T_1 and T_2 will start to conduct current will occur earlier in the cycle and the average current through the generator field increases.

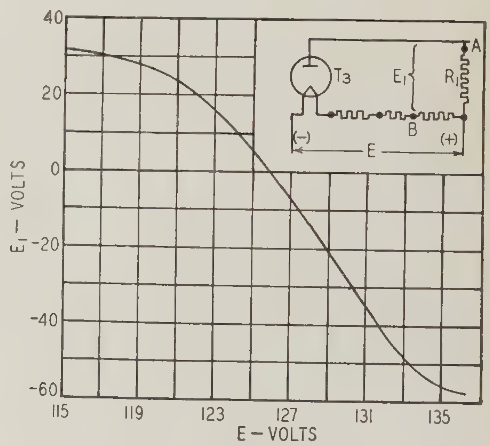
From the curves in figures 4 and 5 it will be apparent that if the generator voltage decreases, the regulator will tend to bring the voltage back toward the original value by increasing the generator field current. Figures 4 and 5 also show that the regulator inherently has a drooping characteristic, which is necessary in order to stabilize the regulator action. To prevent an over-all drooping characteristic it becomes necessary automatically to recalibrate or compound the regulator. This is done as shown in figure 2 by passing the generator field current through part of the resistor which is connected in series with the cathode of tube T_3. The voltage drop produced by the field current across resistor BD increases the effective resistance in series with the cathode, and causes the regulator to increase the generator voltage to its normal value. On account of the inductance of the generator field winding there is a slight delay in the compounding action and therefore no instability or hunting of the regulator occurs.

Performance of Regulator

The regulator was tested with a 5-kw 125-volt 1750-rpm d-c generator. The field resistance was 87 ohms and the field current at no load 0.92 ampere. When the generator was connected as a shunt machine the regulation from no load to full load was as shown in curve A in figure 6. With the regulator in control and connected for zero compensation the regulator had a drooping characteristic as shown by curve B. With compensation, the regulation from no load to full load was practically a straight line (curve C). Tests were also made with the series field of the generator connected to give partial compounding as shown by curve A of figure 7. Without compensation the regulator had only a slightly drooping characteristic as illustrated by curve B. When the same compensating adjustment as used in figure 6 was used the regulator had a slightly rising characteristic as shown by curve C of figure 7. An intermediate compensating adjustment gave flat no load to full load regulation.

The sensitivity of this regulator as the generator load is varied is better than $\pm$ 0.1 per cent if the compensation is properly adjusted. Variations in the voltage of the a-c supply affect the regulated voltage slightly; a 10 per cent increase in alternating voltage increases the regulated voltage $^1/_2$ of one per cent. Variations in a-c supply frequency within commercial limits do not affect the regulation. The over-all sensitivity of the regulator is therefore $\pm$

Fig. 4. Curve of relation of voltage E_1 between points A and B to supply voltage E



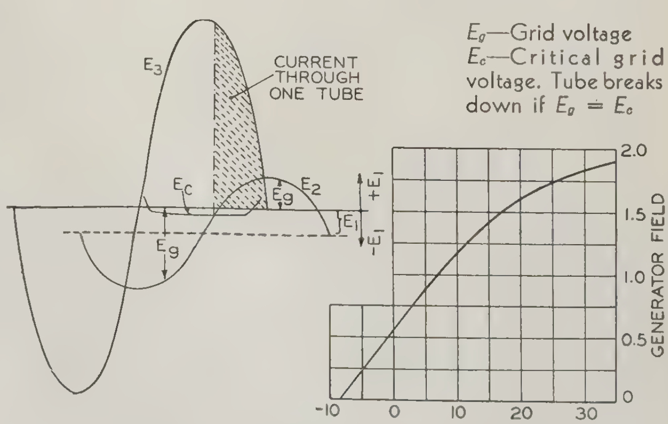


Fig. 5. Control characteristic of grid-controlled arc-discharge tube

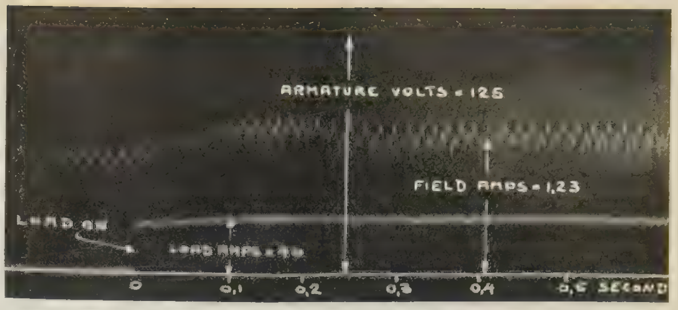


Fig. 8. Oscillogram showing regulation when full load is connected to a 5 kw generator

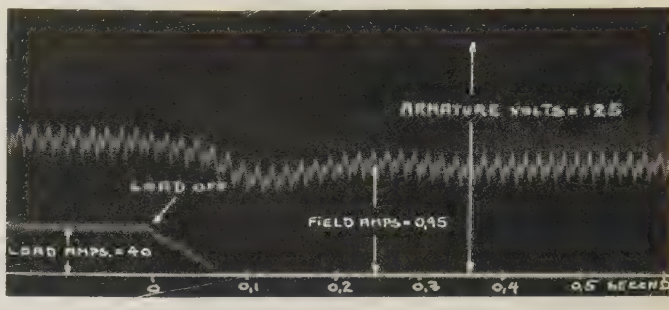


Fig. 9. Oscillogram showing regulation when full load is disconnected from a 5 kw generator

0.5 per cent, which is better than for most electromagnetic regulators now on the market.

The quick response characteristic of this regulator is illustrated by the oscillograms in figures 8 and 9. Figure 8 shows the operation of the regulator when full load is connected to the 5 kw generator. Figure 9 shows the regulator action when full load is disconnected.

The grid-controlled arc-discharge tubes shown in figure 1 each have a rating of 4 amperes average current. Tubes having a rating of 6 amperes may be used, and the regulator may therefore be applied to generators having maximum field currents up to 10 amperes.

Tube Failure

An important factor in the design of regulating equipment is to arrange the circuits so that in case of failure of any of the vital and vulnerable control elements, no appreciable change in regulated voltage should occur, or if this cannot be accomplished to make provisions so that excessive overvoltage is prevented. Electromagnetic type vibrating regulators do not meet this requirement because the regulated voltage may go abnormally high if the vibrating contacts should stick or weld together. The regulator shown in figure 2 does not have this characteristic.

The diode T_3 is operated with a cathode voltage of 3.8 volts although the nominal rating is 5 volts, thus assuring long tube life. Failure of this tube is caused by burning out of the cathode. When this happens voltage E_1 between A and B in figure 2 becomes zero and the current through tubes T_1 and T_2 therefore remains constant at 0.6 ampere as indicated by figure 5. By adjusting R_4 in figure 2 the phase angle of E_2 relative to E_3 may be varied. Increasing R_4 causes E_2 to lag more and causes the field current corresponding to $E_1 = 0$ in figure 5 to decrease. It is therefore possible to adjust the regulator so that in case of failure of tube T_3 any predetermined value of generator field current will result.

Tubes T_1 and T_2 usually fail as the result of a gradual decrease in emission. Before complete failure occurs a slight decrease in regulator sensitivity is observed and arrangements can therefore be made to replace the defective tube. Sudden failure of these tubes may occur occasionally, either by loss of grid control or by leakage of air into the tube. If the grid control is lost the defective tube will act as a straight rectifier, but due to the inductance of the generator field winding, loss of field current control does not result because complete current control is obtained by grid control of the other tube. In case of leakage of air into one tube the regulator voltage will drop to practically residual value.

Application of Regulator

It is felt that the regulator described in this paper is superior to most types of electromagnetic regulators in regard to increased sensitivity, increased speed of response, increased reliability, and decreased maintenance, and therefore should prove useful in d-c regulator applications where an auxiliary source of alternating voltage is available, which includes all installations of a-c motor driven d-c generators.

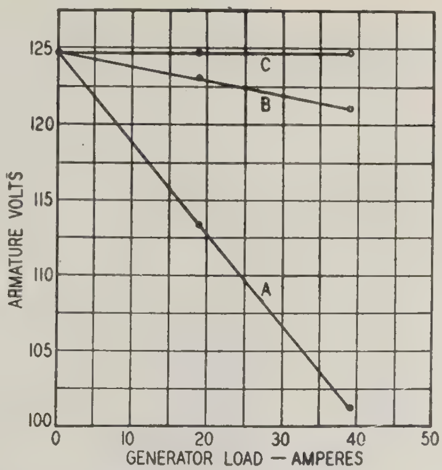


Fig. 6. Regulation curves, no series field

A—No regulator

B—Regulator without compensation

C—Regulator with compensation

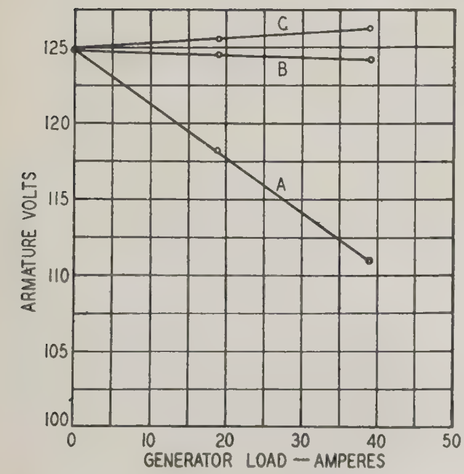


Fig. 7. Regulation curves with series field

A—No regulator

B—Regulator without compensation

C—Regulator with compensation

Dyadic Algebra Applied to 3 Phase Circuits

By
A. PEN-TUNG SAH
ASSOCIATE A.I.E.E.
National Tsing Hua Univ., Peiping, China

This paper discusses and brings together the basic principles and relations necessary for the practical solution of problems involving 3 phase networks by the dyadic algebra developed by Gibbs. Emphasis is placed more on the utility of the method and the similarity between the new relations and those already well established for single phase circuits than on mathematical details of deduction or proof, which can be found elsewhere.

RECENTLY there has appeared in the literature a number of papers employing tensors,[7,8] matrices,[3–6] or dyadics[9–14] to solve electric circuit problems. The fundamental idea of each of these methods is inherently the same, namely, to use either a tensor, a matrix, or a dyadic to describe completely the impedance of the network. It is believed, however, that when 3-phase networks are to be analyzed, the dyadic method of approach is the easiest and the most advantageous. Among the reasons in favor of the dyadic method may be mentioned the very important fact that a complete theory of dyadics with their practical applications to geometry and physics has been worked out by Gibbs.[1] Any one who is familiar only with the English language will thus be able to obtain all the required information on the subject by referring to the last 3 chapters of reference 1 and to apply the method to his problems.

As will be shown in this paper, the dyadic method can be applied to the analysis of 3 phase networks in such a way that there is a very striking analogy between the relations of the 3 phase circuit and those involving only single phase quantities. This remarkable similarity of relations is a very desirable point because one can learn the new method rather rapidly by referring back to his stock of old knowledge. Besides laying special stress upon the reducibility of the new relations to and their similarity with those well established, the present discussion will also keep in the front how the physical constants required for the actual solution of a given problem by the dyadic method can be simply and accurately measured. In order to fix ideas and incidentally to bring out features of the new method, experimental data will be presented in a number of instances. Limited space will not permit the detailed proof or demonstration of some of the relations which can be found elsewhere.[8–14]

Three Phase Impedance as an Entity

Suppose a 3 phase apparatus with grounded neutral is given and its performance characteristics are required. The simplest measurements that will yield the desired information completely are the line currents and the line-to-neutral voltages. With these measurements made for every instant of time,

A—Fundamental plane, perpendicular to **u** and passing through the origin

B—Circle, locus for a balanced system of positive or negative sequence

C—Ellipse, locus for an unbalanced system consisting of positive and negative sequence systems only

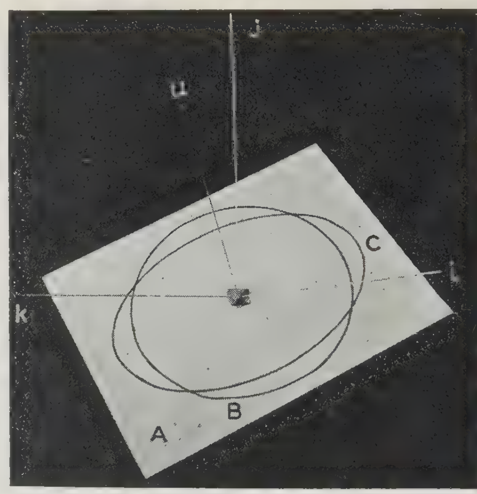


Fig. 1. Model showing the 3 orthogonal axes i, j, and k (phases a, b, and c) the isoclinic direction u, and the fundamental plane

Isoclinic direction is locus for balanced zero sequence system

theoretically it would be possible to write the following 3 simultaneous equations:

$$\begin{aligned} e_a &= z_{aa}i_a + z_{ab}i_b + z_{ac}i_c \\ e_b &= z_{ba}i_a + z_{bb}i_b + z_{bc}i_c \\ e_c &= z_{ca}i_a + z_{cb}i_b + z_{cc}i_c \end{aligned} \qquad (1)$$

in which the subscripts a, b, and c denote the 3 phases and the coefficients z_{aa}, z_{ab}, etc., are functions of resistances, inductances, capacitances, differentiating operator p, time t, angular velocity

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1. For all numbered references see list at end of paper.

ω of the impressed or generated electromotive force, and mechanical angular velocity if different from ω. Whatever these coefficients may be, it is possible to determine them by measurement and, if the structure of the apparatus is known, to calculate them in many cases. In any case, these coefficients are typical of the apparatus under study. Hence, instead of writing the 3 simultaneous equations as in equations 1, it will serve the purpose just as well to write the 9 coefficients z and associate them as an entity with the apparatus, just as one would associate a resistance and an inductance together in the entity known as an impedance.

Notation for Vectors and Dyadics

Editor's Note: Throughout this paper an upright bold character (such as **E**) indicates a vector quantity; a bold face italic character (such as ***E***) indicates a complex quantity.

Before the entity containing the 9 z's is named, let there be arbitrarily introduced 3 orthogonal unit vectors **i**, **j**, and **k**, and a centered dot written between 2 vectors be used to denote their scalar product. Thus equation 1 may be written as:

$$\begin{aligned} e_a\mathbf{i} &= (z_{aa}\mathbf{ii})\cdot(i_a\mathbf{i}) + (z_{ab}\mathbf{ij})\cdot(i_b\mathbf{j}) + (z_{ac}\mathbf{ik})\cdot(i_c\mathbf{k}) \\ e_b\mathbf{j} &= (z_{ba}\mathbf{ji})\cdot(i_a\mathbf{i}) + (z_{bb}\mathbf{jj})\cdot(i_b\mathbf{j}) + (z_{bc}\mathbf{jk})\cdot(i_c\mathbf{k}) \\ e_c\mathbf{k} &= (z_{ca}\mathbf{ki})\cdot(i_a\mathbf{i}) + (z_{cb}\mathbf{kj})\cdot(i_b\mathbf{j}) + (z_{cc}\mathbf{kk})\cdot(i_c\mathbf{k}) \end{aligned} \qquad (1a)$$

In the language of vector algebra, equations 1a may be combined into one vectorial equation as:

$$\mathbf{E} = \boldsymbol{\mathcal{Z}}\cdot\mathbf{I} \qquad (2)$$

in which $\mathbf{E} = e_a\mathbf{i} + e_b\mathbf{j} + e_c\mathbf{k}$ and $\mathbf{I} = i_a\mathbf{i} + i_b\mathbf{j} + i_c\mathbf{k}$ are directed lines in a 3 dimensional space drawn from the origin of the rectangular co-ordinate system such that their projections on the co-ordinate axes represent respectively the values of the line-to-neutral voltages and the line currents of the 3 phases at the instant under consideration. As the operator that changes one vector into another has been called by Gibbs a dyadic, the operator $\boldsymbol{\mathcal{Z}}$ given by

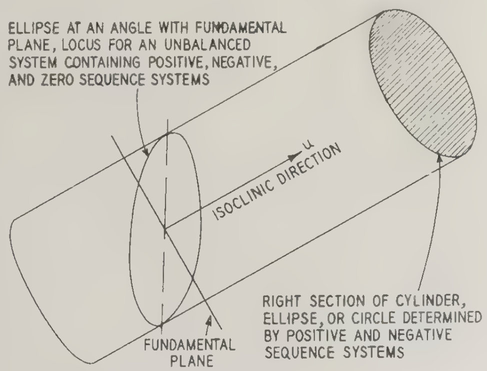


Fig. 2. Unbalanced 3 phase system containing fundamental frequency only

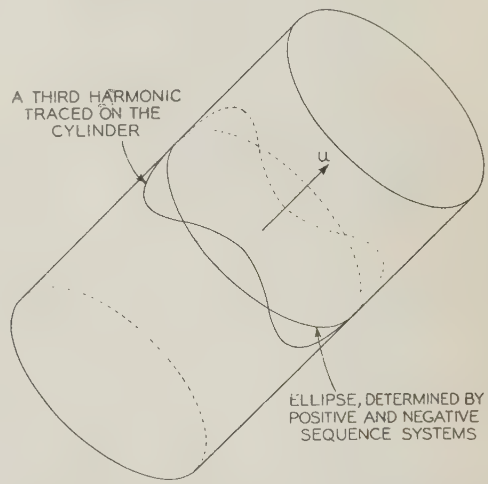
$$\boldsymbol{\mathcal{Z}} = \left\{\begin{aligned} &z_{aa}\mathbf{ii} + z_{ab}\mathbf{ik} + z_{ac}\mathbf{ik} \\ &z_{ba}\mathbf{ji} + z_{bb}\mathbf{jj} + z_{bc}\mathbf{jk} \\ &z_{ca}\mathbf{ki} + z_{cb}\mathbf{kj} + z_{cc}\mathbf{kk} \end{aligned}\right\} \qquad (3)$$

will be called the impedance dyadic of the 3 phase apparatus. In many cases it will be found convenient to group the vectors in a dyadic such as equation 3 into the sum of 3 terms (or less if possible). However, for the purpose of this paper, the nonion form is more desirable and to save labor in writing and printing, the convention will be adopted to abbreviate equation 3 by omitting all the unit vectors and the plus signs and retaining the 9 coefficients in their positions in a square array enclosed in double bars as follows:

$$\boldsymbol{\mathcal{Z}} = \begin{Vmatrix} z_{aa} & z_{ab} & z_{ac} \\ z_{ba} & z_{bb} & z_{bc} \\ z_{ca} & z_{cb} & z_{cc} \end{Vmatrix} \qquad (4)$$

There should not be any difficulty or confusion in recognizing which 2 unit vectors are associated with any one of the coefficients in this array if

Fig. 3. Three phase system containing positive (or negative) sequence system and balanced third harmonic



the above convention is followed. Note that the order of the unit vectors must not be changed.

It has already been stated that the 3 unit vectors **i**, **j**, and **k** were introduced arbitrarily. In a 3 phase circuit one might object to this arbitrariness because there is nothing in the network to suggest the idea of direction in space, although one would readily grant that the 3 voltages or the 3 currents form 2 triad groups of numbers or functions. However, to those who are familiar with the origin of the use of plane vectors in ordinary a-c theory, it might also be said that there was nothing in the a-c network to suggest a direction, and yet present-day practice has fully justified the utility of plane vector diagrams. Thus from the viewpoint of an engineer, the objection to introducing some extraneous geometrical ideas by regarding e_a, e_b, e_c or i_a, i_b, i_c as the projections of a vector would no longer hold, provided useful results could be obtained by such a consideration. True it is that there will be geometrical properties in such a representation which do not have any physical meaning in the network, but here, as in many other applications, one has to be guided by the physics of the problems rather than by the mathematics.

Isoclinic Unit Vector and Fundamental Plane

The fruitfulness of considering the voltages and the currents as vectors and the 3 phase impedances as dyadics will be partly evident when the loci described by the ends of the vectors in several simpler cases are considered. Before discussing these, it will be necessary to introduce at this point an ex-

ceedingly useful unit vector, which, on account of its being equally inclined to the 3 orthogonal reference axes, will be called the isoclinic unit vector. This vector will be given the symbol **u** and is defined by the equation

$$\mathbf{u} = (1/\sqrt{3})(\mathbf{i} + \mathbf{j} + \mathbf{k}) \tag{5}$$

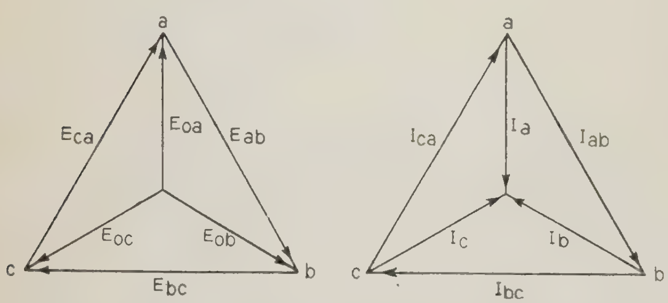
The plane passing through the origin and perpendicular to **u** will be called the fundamental plane. In terms of the isoclinic direction and the fundamental plane, the geometry of many curves corresponding to familiar 3 phase systems can be described briefly as follows (figures 1, 2, and 3):

a. For a balanced system of sinusoidal voltages or currents such as given by the vector

$$\mathbf{I} = I\,\{\sin(\omega t)\mathbf{i} + \sin(\omega t - 120°)\,\mathbf{j} + \sin(\omega t + 120°)\,\mathbf{k}\} \tag{6}$$

its end describes a circle on the fundamental plane with center at the origin. The radius of the circle is $\sqrt{3}$ times the effective value of the phase quantity, i. e., $I/\sqrt{2}$ in the above case. When it is recalled that in single phase circuits a rotating vector of constant length is at the basis of the ordinary vector diagram used in a-c theory, the circular locus in the balanced case is exactly what one would expect.

b. For an unbalanced system of sinusoidal quantities of fundamental frequency which does not have a zero sequence component,



Figs. 4 and 5. Diagrams of voltages and currents in a balanced 3 phase system

for example, line-to-line voltages or line currents in systems with neutral points not grounded, whose vector equation may be written as:

$$\mathbf{I} = I_a \sin(\omega t + a)\,\mathbf{i} + I_b \sin(\omega t + b)\,\mathbf{j} + I_c \sin(\omega t + c)\,\mathbf{k} \tag{7}$$

with the restriction that:

$$\mathbf{u}\cdot\mathbf{I} = 0 \tag{7a}$$

the end of the vector will describe an ellipse on the fundamental plane. The semimajor and the semiminor axes of the ellipse are given respectively by:

$$A = \sqrt{3}\,(P + N) \qquad B = \sqrt{3}\,(P - N) \tag{7b}$$

in which P and N denote respectively the effective value of the positive and the negative sequence quantity as originally defined by Fortescue.[2] It is of interest to note here that if the definition of the sequence quantities had been $\sqrt{3}$ times greater than what is now generally used, the extra factor $\sqrt{3}$ in this case would not appear. Other advantages of using the larger value for the sequence quantities have been discussed elsewhere.[11]

c. The 2 cases just cited are only special cases under the general heading that whenever the sum of the components is zero for all times, the end of the vector lies entirely on the fundamental plane.

d. When the components of the vector do not sum up to zero, i. e., when a zero sequence component is present, the vector will describe in general a curve in space. For sinusoidal systems of fundamental frequency only, this curve is an ellipse making an angle with the fundamental plane. The ellipse may be considered as that cut by a plane from a right elliptical cylinder (which would be circular if either the positive or the negative sequence system does not exist) having the **u** direction as its axis. In case the zero sequence system is due to a balanced system of third harmonics and/or their multiples, the curve will be a sinoid traced on the aforesaid cylinder (figure 3) while the cross section of the cylinder cut by the fundamental plane will be changed in shape according to the type of the positive and the negative sequence systems existing.

Isoclinic Unit Vector in Star-Delta and Delta-Star Transformations

The geometrical relations summarized in the preceding section can be deduced rather easily by making use of the dot product of **u** with the vector under consideration. When delta-star or star-delta relations are to be discussed, it will be found that the cross or the vector product involving **u** is exceedingly useful and simple.

Consider the vector

$$\mathbf{E}_a = e_a\mathbf{i} + e_b\mathbf{j} + e_c\mathbf{k} \tag{8}$$

whose components e_a, e_b, e_c denote the line-to-ground voltages of the 3 phases. No matter what their values are at any instant, the line-to-line voltages at the same instant are:

$$e_{bc} = e_c - e_b \qquad e_{ca} = e_a - e_c \qquad e_{ab} = e_b - e_a \tag{8a}$$

which, when taken as the components of a vector $\mathbf{E}_{bc}$, will enable $\mathbf{E}_{bc}$ to be written simply as:

$$\mathbf{E}_{bc} = \sqrt{3}\,\mathbf{u}\times\mathbf{E}_a \tag{9}$$

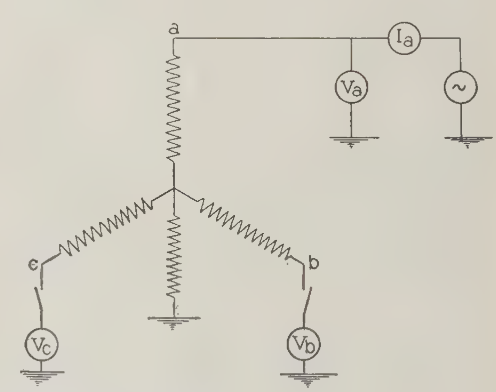
The geometrical meaning of the above is that the vector $\mathbf{E}_{bc}$ is perpendicular to both **u** and $\mathbf{E}_a$ and its length is $\sqrt{3}$ times the component of $\mathbf{E}_a$ that is perpendicular to **u**. The striking resemblance of equation 9 to that in a balanced system is noteworthy. Referring to figure 4, which gives the usual vector diagram of a balanced system of voltages, it is seen that

$$\boldsymbol{E}_{bc} = \boldsymbol{E}_{oc} - \boldsymbol{E}_{ob} = \sqrt{3}\,j\boldsymbol{E}_{oa} \tag{10}$$

in which the letters $\boldsymbol{E}$ denote complex quantities, the j in equation 10 and the $(\mathbf{u}\,\times)$ in equation 9 both denoting rotations through 90 degrees. (Bold characters such as $\boldsymbol{E}$ indicate complex quantities throughout this paper.)

In a similar manner, for a delta system of currents

Fig. 6. Connection diagram for measuring coefficients of impedance dyadic



i_{bc}, i_{ca}, and i_{ab} when combined into a vectorial current as

$$\mathbf{I}_{bc} = i_{bc}\mathbf{i} + i_{ca}\mathbf{j} + i_{ab}\mathbf{k} \tag{11}$$

the corresponding line currents feeding into the delta network may be considered as the components of a current vector given by

$$\mathbf{I}_a = (i_{ab} - i_{ca})\mathbf{i} + (i_{bc} - i_{ab})\mathbf{j} + (i_{ca} - i_{bc})\mathbf{k} \tag{11a}$$

or

$$\mathbf{I}_a = \sqrt{3}\,\mathbf{u} \times \mathbf{I}_{bc} \tag{12}$$

which is entirely analogous to a relation similar to that of equation 10 when the system is balanced (figure 5).

There are 2 points about equations 9 and 12 deserving special attention. The first is that in these relations the sense of the vector $\mathbf{E}_{bc}$ or $\mathbf{I}_a$ is tacitly assumed to be such that these relations apply. The second point is that to determine the line-to-line voltages from the line-to-ground voltages or the line currents from the delta currents, the results are unique as given respectively by equations 9 and 12, while the converse is not unique. In other words it is not possible to determine uniquely the line-to-neutral voltages from line-to-line values, nor the delta currents from line currents, unless the point at ground potential is known in the first instance, or the value of the circulating current in the delta is given in the second.

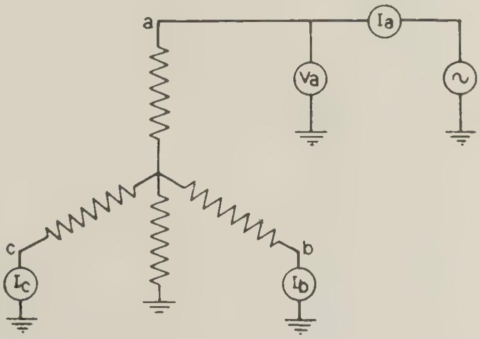


Fig. 7. Connection diagram for measuring coefficients of admittance dyadic

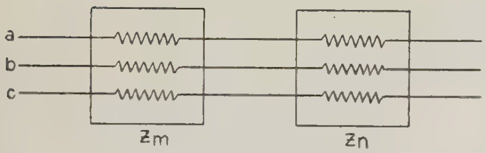


Fig. 8. Three phase impedances in series

Impedance Dyadic and Its Experimental Determination

From the set of simultaneous equations 1, it is readily seen that the z's with the same 2 subscripts are self-impedances and the z's with 2 different subscripts are mutual impedances. In most cases it is a very simple matter to measure them in the laboratory. For instance, with lines b and c open and a single phase voltage $\boldsymbol{V}_a$ applied between line a and the ground, the magnitude of the 3 voltages $\boldsymbol{V}_a$, $\boldsymbol{V}_b$, $\boldsymbol{V}_c$ and the line current $\boldsymbol{I}_a$ together with their phase relations can be measured in the usual way, and as $\boldsymbol{I}_b$ and $\boldsymbol{I}_c$ are both zero, the following complex values are easily calculated:

$$\boldsymbol{Z}_{aa} = \frac{\boldsymbol{V}_a}{\boldsymbol{I}_a} \quad \boldsymbol{Z}_{ba} = \frac{\boldsymbol{V}_b}{\boldsymbol{I}_a} \quad \boldsymbol{Z}_{ca} = \frac{\boldsymbol{V}_c}{\boldsymbol{I}_a} \tag{13}$$

The other z's can be determined in a similar way by applying voltages to phases b and c only. Just to give an idea of what may be expected in such measurements, the following 2 numerical examples will be cited.

Example 1 is a complicated static network with inductive reactances having negligible resistances. The value actually measured was

$$\boldsymbol{Z} = j\begin{Vmatrix} 14.70 & 11.98 & 11.98 \\ 11.74 & 12.25 & 9.65 \\ 11.93 & 9.84 & 11.12 \end{Vmatrix}$$

which was averaged to

$$\boldsymbol{Z} = j\begin{Vmatrix} 14.70 & 11.86 & 11.95 \\ 11.86 & 12.25 & 9.75 \\ 11.95 & 9.75 & 11.12 \end{Vmatrix} \tag{14}$$

The averaging was undertaken because in a static network the mutual impedance coefficients are always equal, i. e., $z_{mn} = z_{nm}$ for all values of m and n.

Example 2 is a phase wound induction motor running at synchronous speed with rotor terminals all short-circuited. The value actually measured was

$$\boldsymbol{Z} = \begin{Vmatrix} 6.23\angle\ 80.5^\circ & 4.52\angle -144.3^\circ & 4.52\angle -\ 50.0^\circ \\ 4.64\angle -\ 48.2^\circ & 6.14\angle\ 80.5^\circ & 4.66\angle -147.2^\circ \\ 4.78\angle -141.2^\circ & 4.66\angle -\ 46.0^\circ & 6.35\angle\ 80.3^\circ \end{Vmatrix} \tag{15}$$

which should be averaged to give a dyadic of the following form:[14]

$$\begin{Vmatrix} A & C & B \\ B & A & C \\ C & B & A \end{Vmatrix} \tag{15a}$$

and in the example cited, the constants may be taken as:

$$A = 6.23\angle 80.4^\circ \quad B = 4.61\angle -48.1^\circ \quad C = 4.66\angle -144.2^\circ \tag{15b}$$

It may be noted that if all resistances were negligible, theoretically B and C would have the same magnitude but negative angles that sum up to -180 degrees.[14]

Admittance Dyadic and Its Determination

Equations 1 give voltage relations. It is quite obvious that current relations might have been used instead. Thus, the line currents can be written in terms of the line-to-neutral voltages as follows:

$$\begin{aligned} i_a &= y_{aa}e_a + y_{ab}e_b + y_{ac}e_c \\ i_b &= y_{ba}e_a + y_{bb}e_b + y_{bc}e_c \\ i_c &= y_{ca}e_a + y_{cb}e_b + y_{cc}e_c \end{aligned} \tag{16}$$

in which the 9 y's can be either measured directly or expressed in terms of the z's of equations 1. To express them in terms of the latter, or *vice versa*, the formula from the theory of determinants is simplest. It is:

$$y_{ij} = \frac{A_{ji}}{D} \tag{17}$$

in which A_{ji} is the cofactor of z_{ij} in the determinant formed of the z's as they stand in equations 1 and D is the determinant. When the 9 y's are also recognized as an entity and called the admittance dyadic, $\mathfrak{Y}$, then equations 16 may be written as

$$\mathbf{I} = \mathfrak{Y} \cdot \mathbf{E} \tag{18}$$

wherein the admittance dyadic is given by:

$$\mathfrak{Y} = \begin{Vmatrix} y_{aa} & y_{ab} & y_{ac} \\ y_{ba} & y_{bb} & y_{bc} \\ y_{ca} & y_{cb} & y_{cc} \end{Vmatrix} = \mathfrak{Z}^{-1}$$

$$= \frac{1}{D} \begin{Vmatrix} (z_{bb}z_{cc} - z_{bc}z_{cb}) & (z_{ac}z_{cb} - z_{ab}z_{cc}) & (z_{ab}z_{bc} - z_{ac}z_{bb}) \\ (z_{bc}z_{ca} - z_{ba}z_{cc}) & (z_{aa}z_{cc} - z_{ac}z_{ca}) & (z_{ac}z_{ba} - z_{aa}z_{bc}) \\ (z_{ba}z_{cb} - z_{bb}z_{ca}) & (z_{ab}z_{ca} - z_{aa}z_{cb}) & (z_{aa}z_{bb} - z_{ab}z_{ba}) \end{Vmatrix} \tag{19}$$

Physically the y's with the same 2 subscripts are self-admittances and those with 2 different subscripts are mutual admittances. In static networks and symmetrical machines, the determination of the y's by steady state measurements is very simple. Incidentally, here is an experimental method of evaluating the reciprocal of a matrix by electric measurements. For instance, with lines b and c grounded through an ammeter (figure 7), a single phase voltage $\boldsymbol{V}_a$ is applied between line a and the ground as shown. From the values of the currents $\boldsymbol{I}_a$, $\boldsymbol{I}_b$, and $\boldsymbol{I}_c$ and their phase angles with $\boldsymbol{V}_a$, the following complex values for the coefficients are at once computed:

$$\boldsymbol{Y}_{aa} = \frac{\boldsymbol{I}_a}{\boldsymbol{V}_a} \quad \boldsymbol{Y}_{ba} = \frac{\boldsymbol{I}_b}{\boldsymbol{V}_a} \quad \boldsymbol{Y}_{ca} = \frac{\boldsymbol{I}_c}{\boldsymbol{V}_a} \tag{20}$$

for $\dot{\boldsymbol{V}}_b$ and $\dot{\boldsymbol{V}}_c$ are both zero. The other y's can be measured in a similar way. The measured value for the static network of example 1 gave

$$\mathfrak{Y} = -j \begin{Vmatrix} 0.738 & -0.286 & -0.527 \\ -0.271 & 0.358 & 0.062? \\ -0.519 & 0.062? & 0.668 \end{Vmatrix} \tag{21}$$

while the calculated value in accordance with the reciprocal formula of either equation 17 or 19 using the averaged value of equation 13 yielded

$$\mathfrak{Y} = -j \begin{Vmatrix} 0.706 & -0.263 & -0.522 \\ -0.263 & 0.354 & -0.029 \\ -0.522 & -0.029 & 0.673 \end{Vmatrix} \tag{22}$$

It will be noted that the calculated and the measured values agree fairly satisfactorily except the value 0.062 indicated by a question mark in equation 21. In this case it was found that the effect of the meter impedance was considerable because of the smallness of the admittance coefficient, and so the value should not be relied upon too much.

Before leaving the subject of single units of 3 phase impedance or admittance, it may be stated that neither equations 1 nor 16 nor the reciprocal relation given by equations 17 or 19 is new. However, the novelty from an engineer's viewpoint is that the 9 z's and 9 y's have been considered as 2 entities. The value of the recognition accorded to these as 2 entities does not end here, because they can be combined in parallel or in series by formulas that are exactly the same as the ordinary ones used in single phase circuits. This topic of equivalent 3 phase impedances will next be given attention.

Equivalent 3 Phase Impedances and Admittances

When 2 sets of 3 phase impedances are connected in series as shown in figure 8, the equivalent impedance dyadic is obtained from the separate impedance dyadics by adding corresponding coefficients. This follows at once from equations 1. Similarly from equations 16, it may be stated that when 2 sets of 3 phase impedances are connected in parallel as shown in either a or b of figure 9 without imposing the restriction that the sum of the line currents in either one is zero, then the equivalent impedance dyadic $\mathfrak{Z}$ of the combination may be evaluated as the reciprocal of the equivalent admittance by the usual formula, while the equivalent admittance dyadic is simply the sum of the separate admittance dyadics. It is very interesting to note here that the following reduction formula, which is useful in some cases, holds just as in ordinary circuits:

$$\mathfrak{Z} = (\mathfrak{Z}_m^{-1} + \mathfrak{Z}_n^{-1})^{-1} = \mathfrak{Z}_m \cdot (\mathfrak{Z}_m + \mathfrak{Z}_n)^{-1} \cdot \mathfrak{Z}_n$$
$$= \mathfrak{Z}_n \cdot (\mathfrak{Z}_m + \mathfrak{Z}_n)^{-1} \cdot \mathfrak{Z}_m \tag{23}$$

provided the invalidity of the commutative law of multiplication in dyadic or matrix algebra is recognized, or more specifically, the term that is usually written in the denominator in ordinary circuit theory must remain in the middle of the product.

To show to what extent the calculated and the measured equivalent impedances agree, 2 rather unusual static networks containing inductive reactances with negligible resistances were set up. The procedure already described for the determination of the z's in a preceding section was used in measuring the coefficients of the impedance dyadics when they were taken as separate 3 phase units as well as when they were connected in parallel as shown in figure 9b. When considered as separate units, the impedance dyadics were respectively (after averaging the coefficients facing each other across the leading diagonal)

$$\mathfrak{Z}_m = j \begin{Vmatrix} 16.9 & 11.2 & 9.00 \\ 11.2 & 12.5 & 9.08 \\ 9.00 & 9.08 & 7.54 \end{Vmatrix} \tag{24a}$$

and

$$\mathfrak{Z}_n = j \begin{Vmatrix} 6.43 & 5.02 & 4.91 \\ 5.02 & 4.88 & 4.94 \\ 4.91 & 4.94 & 11.48 \end{Vmatrix} \tag{24b}$$

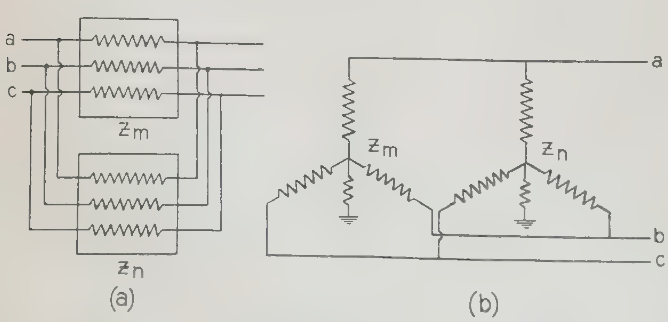


Fig. 9. Three phase impedances in parallel

The calculated value for these in parallel was:

$$\mathfrak{Z} = j\begin{Vmatrix} 4.55 & 3.44 & 2.72 \\ 3.44 & 3.36 & 2.58 \\ 2.72 & 2.58 & 2.75 \end{Vmatrix} \tag{25a}$$

and the value measured was:

$$\mathfrak{Z} = j\begin{Vmatrix} 4.53 & 3.41 & 2.73 \\ 3.42 & 3.33 & 2.58 \\ 2.72 & 2.57 & 2.65 \end{Vmatrix} \tag{25b}$$

showing that the agreement is quite satisfactory.*

Equivalent Impedance if One of the Impedances Is Not Grounded

The reciprocal relation given by equations 17 or 19 is valid only when the impedance is grounded. In case of ungrounded neutrals, it is permissible to think of the neutral as being grounded through a large common impedance N (figure 10) which in the final evaluation is eventually made infinite. In this way it can be proved[12] by making use of the properties of double multiplication of dyadics that the following formula is valid:

$$\mathfrak{Y} = -\frac{(\sqrt{3}\,\mathbf{u} \times \mathfrak{Z} \times \sqrt{3}\,\mathbf{u})_t}{(\sqrt{3}\,\mathbf{u} \times \mathfrak{Z})_{2s}} \tag{26}$$

The notation in this equation, except the subscript t to denote the "transpose" of a dyadic, is entirely due to Gibbs and is admirably neat and short. The vector $\mathbf{u}$ is the isoclinic unit vector that has been discussed before and the cross product is to be carried out in accordance with usual definition. The subscript $2s$ in the denominator means the "scalar of the second" of the dyadic within the parenthesis—the quantity being a number, of course. To those not familiar with Gibbs' notation, the operation of cross multiplying the dyadic $\mathfrak{Z}$ on the left and on the right by the vector $\sqrt{3}\,\mathbf{u}$ is equivalent to multiplication of the matrix formed from $\mathfrak{Z}$ by the following skew-symmetrical matrix on the left and on the right:

$$\begin{Vmatrix} 0 & -1 & 1 \\ 1 & 0 & -1 \\ -1 & 1 & 0 \end{Vmatrix} \tag{27}$$

The denominator in equation 26, when using matrix terminology, means simply that the sum of the diagonal minors of the matrix enclosed within the parenthesis is to be taken. To illustrate the actual calculations, the following detailed procedures will be given, using the $\mathfrak{Z}_m$ of equation 24a as a numerical example.

$$\sqrt{3}\,\mathbf{u} \times \mathfrak{Z}_m = j\begin{Vmatrix} 9.00 - 11.2 & 9.08 - 12.5 & 7.54 - 9.08 \\ 16.9 - 9.00 & 11.2 - 9.08 & 9.00 - 7.54 \\ 11.2 - 16.9 & 12.5 - 11.2 & 9.08 - 9.00 \end{Vmatrix} \tag{28a}$$

$$\sqrt{3}\,\mathbf{u} \times \mathfrak{Z}_m = j\begin{Vmatrix} -2.20 & -3.42 & -1.54 \\ 7.90 & 2.12 & 1.46 \\ -5.70 & 1.30 & 0.08 \end{Vmatrix} \tag{28b}$$

* All the numerical data in this paper are cited not for the purpose of justifying the operations, but rather with a view to showing how easily and accurately the constants needed in the theory can be determined by ordinary instruments and connections.

From the way that the coefficients in equation 28a sum up, the following practical rule may be given to evaluate $\sqrt{3}\,\mathbf{u} \times \mathfrak{Z}$:

"Shift the coefficients in $\mathfrak{Z}$ up once and down once in each column. Retain the same sign for all down-shifts and reverse the signs for all up-shifts. Find the algebraic sum of the 2 terms for each position."

To find $-\sqrt{3}\,\mathbf{u} \times \mathfrak{Z} \times \sqrt{3}\,\mathbf{u}$ from $(\sqrt{3}\,\mathbf{u} \times \mathfrak{Z})$ a similar practical rule may be stated by changing the words "up" and "down" into "right" and "left," respectively, and the word "column" into "row." Thus from equation 28b, it is found that

$$-\sqrt{3}\,\mathbf{u} \times \mathfrak{Z}_m \times \sqrt{3}\,\mathbf{u} = j\begin{Vmatrix} -1.54+3.42 & -2.20+1.54 & -3.42+2.20 \\ 1.46-2.12 & 7.90-1.46 & 2.12-7.90 \\ 0.08-1.30 & -5.70-0.08 & 1.30+5.70 \end{Vmatrix}$$

$$= j\begin{Vmatrix} 1.88 & -0.66 & -1.22 \\ -0.66 & 6.44 & -5.78 \\ -1.22 & -5.78 & 7.00 \end{Vmatrix} \tag{28c}$$

which is also the value of the dyadic given in the numerator of equation 26, for equation 28c is self-transposed.

Since the denominator in equation 26 is simply the sum of the minors of the leading diagonal of $(\sqrt{3}\,\mathbf{u} \times \mathfrak{Z})$, from equation 28$b$

$$(\sqrt{3}\,\mathbf{u} \times \mathfrak{Z}_m)_{2s} = j\begin{vmatrix} -2.20 & -3.42 \\ 7.90 & 2.12 \end{vmatrix} + j\begin{vmatrix} 2.12 & 1.46 \\ 1.30 & 0.08 \end{vmatrix} + j\begin{vmatrix} -2.20 & -1.54 \\ -5.70 & 0.08 \end{vmatrix}$$

$$= -11.66 \tag{28d}$$

Dividing each term of equation 28c by -11.66 will then give the required value of the admittance as indicated by equation 26.

Adding the admittance dyadic $\mathfrak{Y}_m$ thus found to the admittance dyadic of $\mathfrak{Z}_n$ found by equation 19 will give the equivalent admittance of $\mathfrak{Z}_m$ ungrounded in parallel with $\mathfrak{Z}_n$ grounded. Evaluating the reciprocal of this resultant admittance dyadic in the usual way will then yield the required equivalent impedance $\mathfrak{Z}$. The calculated and the measured values for the impedance dyadics of equations 24a and 24b are as follows:

a. $\mathfrak{Z}_m$ ungrounded and $\mathfrak{Z}_n$ grounded

$$\text{Calculated: } j\begin{Vmatrix} 6.23 & 5.08 & 5.18 \\ 5.08 & 4.93 & 4.95 \\ 5.18 & 4.95 & 6.35 \end{Vmatrix} \qquad \text{Measured: } j\begin{Vmatrix} 6.17 & 4.97 & 5.14 \\ 4.97 & 4.90 & 4.93 \\ 5.17 & 5.01 & 6.23 \end{Vmatrix} \tag{29}$$

b. $\mathfrak{Z}_m$ grounded and $\mathfrak{Z}_n$ ungrounded

$$\text{Calculated: } j\begin{Vmatrix} 11.8 & 10.8 & 8.40 \\ 10.8 & 10.9 & 8.35 \\ 8.40 & 8.35 & 7.21 \end{Vmatrix} \qquad \text{Measured: } j\begin{Vmatrix} 12.0 & 10.95 & 8.53 \\ 10.7 & 10.8 & 8.32 \\ 8.55 & 8.45 & 7.11 \end{Vmatrix} \tag{30}$$

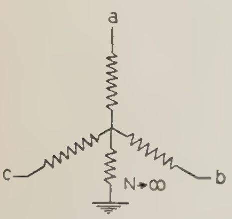
Star-Delta Equivalents for 3 Sets of 3 Phase Impedances

In order that complicated 3 phase networks may be reduced to simpler systems, it will be necessary to know how to change 3 sets of 3 phase impedances connected in star to 3 sets of 3 phase impedances

connected in delta (figure 11) or *vice versa* just as in single phase theory. The required formulas for these transformations resemble very much the well known Kennelly formulas and have been derived elsewhere.[13] Suffice it to say here that with these formulas for equivalent 3 phase networks, all the required information for simplifying 3 phase networks as they stand without resorting to splitting them up into different single phase systems, which procedure is not always simple, is now at hand. It is believed that the solution of simultaneous multiple faults on 3 phase systems by this method will be simpler and more easily understood than it is by the methods used hitherto.

Machines as Coupled Systems

The problem of rotating machines can be studied from the standpoint of the general machine as has been done by Gabriel Kron[7,8] or from the viewpoint of a coupled system.[10,14] For the commoner machines such as the synchronous alternator or motor or the phase wound or squirrel cage induction motor, the latter method is believed to involve less computa-



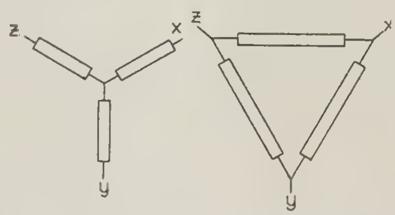


Fig. 10 (left). Three phase impedance with neutral ungrounded

Fig. 11 (right). Star-delta equivalents of 3 sets of 3 phase impedances

tion. Thus, let $\mathbf{E}_a$ be the vector voltage applied to the stator (considered as the armature) of a machine with rotor running and short-circuited. The vector stator current $\mathbf{I}_a$ and the vector rotor current $\mathbf{I}_u$ are related by the following 2 equations which are analogous to those used in single-phase coupled circuits:

$$\begin{aligned} \mathbf{E}_a &= \mathbf{Z}_{aa}\mathbf{I}_a + \mathbf{Z}_{au}\mathbf{I}_u \\ 0 &= \mathbf{Z}_{ua}\mathbf{I}_a + \mathbf{Z}_{uu}\mathbf{I}_u \end{aligned} \tag{31}$$

in which $\mathbf{Z}_{aa}$ is the self-impedance dyadic of the stator when all rotor circuits are open, $\mathbf{Z}_{uu}$ is the self-impedance dyadic of the rotor when all stator circuits are open, and $\mathbf{Z}_{au}$ and $\mathbf{Z}_{ua}$ are the mutual impedance dyadics. By eliminating $\mathbf{I}_u$ it will be found that

$$\mathbf{E}_a = (\mathbf{Z}_{aa} - \mathbf{Z}_{au} \cdot \mathbf{Z}_{uu}^{-1} \cdot \mathbf{Z}_{ua}) \cdot \mathbf{I}_a. \tag{32}$$

in which the dyadic within the parenthesis may be considered as the equivalent impedance of the machine measured from the stator terminals with rotor running and its terminals short-circuited but without excitation. Detailed calculations and measurements on several machines have shown the fruitfulness of this method of analysis.[14] Among the most important results it may be mentioned that for a completely symmetrical machine, the impedance dyadic takes the form:

$$\begin{Vmatrix} A & C & B \\ B & A & C \\ C & B & A \end{Vmatrix} \tag{33}$$

while for a salient pole alternator with only one winding on the rotor, the following 4 dyadics play important rôles:

$$\begin{Vmatrix} 1 & a & a^2 \\ a^2 & 1 & a \\ a & a^2 & 1 \end{Vmatrix} \quad \begin{Vmatrix} 1 & a^2 & a \\ a & 1 & a^2 \\ a^2 & a & 1 \end{Vmatrix} \quad \begin{Vmatrix} 1 & a & a^2 \\ a & a^2 & 1 \\ a^2 & 1 & a \end{Vmatrix} \quad \begin{Vmatrix} 1 & a^2 & a \\ a^2 & a & 1 \\ a & 1 & a^2 \end{Vmatrix} \tag{34}$$

where a and a^2 are the 2 complex cube roots of unity.

Concluding Remarks

From the discussion given in this paper it is quite apparent that the similarity between the dyadic method of analyzing 3 phase networks and that used in ordinary single phase calculations is by no means limited to external forms. The dyadic method of attacking 3 phase problems has actually brought forth new concepts and relations, besides suggesting new problems, which would otherwise be screened behind the present-day avenue of approach to the same problems. The method, it is hoped, has earned its right of existence in engineering and will be nursed to maturity by all electrical engineers interested in circuit analysis. It is also believed that with the practical value of the method demonstrated for 3 phase systems which are more important and well known, one would be in a better position to appreciate the generalizations that would naturally follow.

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Discussions

Of A.I.E.E. Papers—as Recommended for Publication by Technical Committees

On this and the following 42 pages appears all remaining available discussion of papers presented at the A.I.E.E. winter convention, New York, N. Y., January 28–31. Authors' closures, where they have been submitted, will be found at the end of the discussion on their respective papers.

Members anywhere are encouraged to submit written discussion of any paper published in ELECTRICAL ENGINEERING, which discussion will be reviewed by the proper technical committee and considered for possible publication in a subsequent issue. Discussions should be typewritten and submitted in triplicate to C. S. Rich, secretary, technical program committee, A.I.E.E. headquarters, 33 West 39th Street, New York, N. Y.

Silicon Steel in Communication Equipment

Discussion and authors' closure of a paper by C. H. Crawford and E. J. Thomas published in the December 1935 issue, pages 1348–53, and presented for oral discussion at the magnetic materials session of the winter convention, New York, N. Y., January 29, 1936.

J. S. Murray (Follansbee Bros. Co., Follansbee, W. Va.): The company with which the writer is associated is one of the oldest of those manufacturing silicon sheets in the United States, and it is the writer's duty to devote a large part of his time to the subject of development and application of silicon steel in the electrical industry. It is believed that the paper presented by C. H. Crawford and E. J. Thomas is one of the most practical papers yet presented on this subject. In fact, the very clear discussion of the requirements of silicon steel for communication equipment is equally applicable in a large measure to the requirements prevailing in the electrical industry generally for this product. The writer wishes to inquire whether standard test specimens were used in determining the properties shown in table I of the paper, especially the physical properties.

E. L. Schwartz (Bell Telephone Laboratories, Inc., New York, N. Y.): In discussing the nickel-iron alloys, the statement is made in the paper by C. H. Crawford and E. J. Thomas that a permalloy containing approximately 80 per cent nickel has about $1^1/_2$ times the permeability of the 45–50 per cent nickel alloy, but the cost is twice that of the latter. It is not stated at what frequency and flux density this comparison has been made. The writer assumes it refers to low flux densities and low frequencies since several references are made to the advantages of the use of the 45–50 per cent nickel alloy in apparatus operating at low flux densities, particular reference being made to audio frequency transformers. It might be inferred from the comparison that equivalent results might be more economically obtained through the use of a proportionally larger amount of the lower permeability material. This may be the case in certain classes of apparatus, although it does not generally occur in the development of high quality audio frequency input transformers. This is due to the fact that, in order to meet the desired uniformity of transmission of the higher frequencies in this type of apparatus, low distributed capacities in the windings are essential. This in turn makes necessary as small magnetic structures as possible. With the lower permeability nickel iron alloys a core structure sufficiently large to suit the required transmission of the lower frequencies often would be of such size as to result in distributed winding capacitances too large for uniform transmission of the higher frequencies. In this connection the increased permeability of the 80 per cent nickel permalloy has made its use extremely advantageous in the development of communication transformers, in which transmission as uniform as possible at a reasonable cost is desired over a wide frequency range. The use of this material has made possible the development and commercial production of a wide variety of high quality audio frequency transformers, a result which otherwise could not have been obtained.

Reference is also made to the fact that the magnetic properties of the nickel-iron alloys change adversely due to mechanical shock and strain. Although change of this nature does occur and must be given due consideration in the use of the material, the writer would like to add that in communication transformer work in general it does not constitute a serious design or production problem.

With respect to the extent of the use of silicon steel and the permalloys in communication transformers it is interesting that over $^9/_{10}$ of such transformers now being developed by the Bell Telephone Laboratories make use of permalloy cores.

P. P. Cioffi (Bell Telephone Laboratories, Inc., New York, N. Y.): The materials that have been considered in this paper are those commercially available at present. It may be expedient to mention at this time the prospects for improving the characteristics of such materials. Already in this meeting it has been reported that the magnetic properties of iron may be enormously improved by high temperature treatment in hydrogen. For example, the writer has repeatedly obtained in this way an initial permeability of 20,000, a maximum permeability of 300,000 and very low values of coercive force and hysteresis loss.

The point the writer wishes to make now is that this same method of heat treatment may be applied to silicon steel as well as many other magnetic materials. By such treatment the initial and maximum permeability of silicon iron have been increased considerably, and the hysteresis loss has been reduced substantially. The resistivity is not changed by the treatment from its high value characteristic of the iron-silicon alloys.

T. D. Yensen (Westinghouse Elec. and Mfg. Co., East Pittsburgh, Pa.): As a general survey of the field, the paper is a valuable contribution, for it describes various grades of materials available, and indicates their general suitability to the needs of the electrical engineer in the communication field. However, in the section on application of the various grades of iron, the paper deals too much in generalities. The writer cannot help feeling that as a symposium paper, it would have been better if the paper had presented more specific data, so as to give something definite on which to base a discussion.

One of its main faults, in the writer's opinion, is that it makes use of trade names of one particular company in describing the various grades of silicon iron on the market, and without stating that this is true. This would lead the reader to suppose that these names are generally accepted among the electrical manufacturers, and this is not the case. Each manufacturer or steel mill has its particular trade names. This also applies to nickel iron.

In connection with the mention of nickel iron, "Hipernik" (50 per cent nickel) certainly should be included with maximum permeabilities of 80,000 to 100,000 and with losses lower than 0.30 watt per pound for $B = 10{,}000$ at a frequency of 60 cycles per second. This has been made in commercial quantities for many years.

As to the future, the writer anticipates the development of iron-silicon alloys much better than those available at present. The determining factors, namely, purity, grain size and grain orientation, and the processes for controlling these factors are fairly well known. It is only a question of the time required to translate this knowledge into commercial practice.

J. P. Barton (American Sheet and Tin Plate Co., Pittsburgh, Pa.): The convention committee is to be congratulated in arranging this symposium on magnetic materials at a time desirable for such a review. With electric power consumption at

its highest value in the history of the country, it is important to note that such a consumption would hardly have been possible without the use of silicon content steels in sheet form for the laminated structures of transformers and rotating machines. The bulky and relatively inefficient machines of the past gradually have evolved into smaller, more efficient, and more graceful machines of the present through the continued improvement in quality of electrical steels.

Since the introduction of the silicon-iron alloys for magnetic purposes about 1903, electrical steel sheets have shown a continued reduction in core loss and improvement in permeability as indicated in figure 1 of the paper. Mechanical properties in the sheets likewise have been improved, and the result is a flat sheet with tight scale, or with little or no surface oxide film, if preferred. About 10 commercial grades are available today in many thicknesses, ranging in silicon content from about $^1/_4$ to $4^1/_2$ per cent. These provide the design engineer with a wide choice of permeability, core loss, physical properties, and initial costs.

The excellent paper covers many applications concerning not only communication equipment but other general fields of electrical engineering. It would be desirable to point out that the core loss values in watts per pound for 29 gauge steel in table I of the paper, are not quite in agreement with the published maximum guaranteed standard value. Some of the values quoted would be more correct for 26 or 24 gauge than for 29 gauge. This is true especially for the lower silicon content grades, for which much higher values are indicated than are guaranteed commercially. Usually the audio transformer grades as mentioned in this paper differ only from the power transformer grades by having a higher permeability in the low flux density ranges, the guaranteed core loss values being the same in both cases.

Higher permeabilities mean higher values of incremental permeability, which is major concern when the laminated core structures are polarized by direct current.

C. H. Crawford and **E. J. Thomas:** In reply to E. L. Schwartz's questions relative to the statment that "A permalloy, which contains approximately 80 per cent nickel has about $1^1/_2$ times the permeability of the 45–50 per cent nickel alloy," the tests were made at 60 cycles with a flux density of 100 lines per square centimeter in the core.

Since the paper was written, another material that is being placed on the market by the Allegheny Steel Company under the trade name of "Mu Metal," and which corresponds to permalloy in that it contains approximately 80 per cent nickel, has come to the authors' attention. "Mu Metal" has an effective permeability of 10,000 at 100 lines per square centimeter measured at 60 cycles per second, or 3 times that of the 45–50 per cent nickel-iron alloy instead of the $1^1/_2$ times previously mentioned.

Table I of this discussion shows comparative effective permeabilities for 4 per cent silicon steel, 45–50 nickel-iron alloy and "Mu Metal" in which the effective permeability is the value of U to be used in the equation $L = KN^2UA/l$. In this equation L is the inductance in henries, N is the number of turns in the coil, A is the cross section of the core in square centimeters, l is the mean length of magnetic circuit in centimeters, and K is a constant.

The statement in the paper that no attention need be paid to leakage reactance in output transformers should be revised to read "little difficulty is encountered normally in securing suitable leakage reactance values."

Table I

Core Density, Lines per Square Centimeter	4 Per Cent Silicon Steel	45–50 Per Cent Nickel Iron	"Mu Metal"
100	900	3,500	10,000
200	1,600	4,300	11,000
600	2,600	6,500	12,800
1,000	3,100	7,600	13,800
4,000	3,500	2,500	11,300
6,000	3,000		37,300

J. S. Murray has raised a question as to the type of specimen used in obtaining the properties listed in table I of the paper. The standard strip steel specimens were used to obtain the data.

T. D. Yensen has raised a question in regard to the trade names of the silicon steels. It was not the authors' intention to use the trade names of any one company, but to select a name for each group of steel of a given silicon content range that would distinguish it for ready reference in the discussion. However, several companies use the trade name "armature" to designate steels of approximately the same silicon content as the armature grade referred to in the paper. Likewise, the other names used to designate grades of steel are used by one or more companies for trade names. To the authors' knowledge, the names used are not all common to any one company.

Present Status of Ferromagnetic Theory

Discussion and author's closure of a paper by R. M. Bozorth published in the November 1935 issue, pages 1251–61, and presented for oral discussion at the magnetic materials session of the winter convention, New York, N. Y., January 29, 1936.

J. J. Smith (General Electric Co., Schenectady, N. Y.): R. M. Bozorth is to be congratulated on the way in which he has succeeded in covering in 10 pages the salient features of our knowledge of the theory of ferromagnetism. The picture he presents although acknowledged as still far from complete, shows sufficient correspondence between the theory and many different experimental data to promise that further work in the directions indicated will increase materially our theoretical background.

There are a few questions that the writer should like to ask. One of these concerns the reference to domains (ELEC. ENGG., v. 54, Dec. 1935, p. 1254). This term is used by many writers on magnetism although it is difficult to get a good picture of what is meant by the term. In the summary of table II of the paper it will be noticed that a single crystal contains 10^8 domains per cubic centimeter. A crystal generally is considered to be a homogeneous structure, but it is obvious that this cannot be true if it is made up of a large number of domains. Further information on these domains would be of interest, particularly with regard to the nature of irregularity in structure that separates one domain from the other and is still consistent with the crystal having homogeneous structure in the usual sense.

The writer should like also to refer to the phenomenon of instability of permeability at low densities that has been called "drift of permeability" by some recent writers. It has been known for a long time that the permeability of ferromagnetic materials for low values of induction is greater if the material is first magnetized at a high flux density and then tested on the way down the magnetization curve than if the same material is tested going up the magnetization curve from an unmagnetized state. For this reason, the standard method of obtaining a magnetization curve is to start at the high values and work down, for this procedure gives more consistent results. These higher values of permeability last for a considerable period of time but the material finally reverts to the lower permeability typical of the unmagnetized state. Bozorth did not refer to this phenomenon in his discussion and the writer wonders if he could add a few words to indicate whether this might be expected on the basis of our present theoretical knowledge.

T. D. Yensen (Westinghouse Elec. and Mfg. Co., East Pittsburgh, Pa.): The writer has read the paper by R. M. Bozorth with a great deal of interest, and has concluded that the paper is a very good presentation and gives a clear picture of the subject. It contains no essentially new matter, and none is to be expected, but so far the writer has seen no paper that presents the subject in a manner that makes this rather difficult subject as easy to grasp as does this one. However, there are a few points in the paper that the writer should like to comment on.

In table I of the paper, the 1915 values for iron are given as 45,000 and 0.3, respectively, for maximum permeability and coercive force and no values are given for iron-silicon alloys except initial permeability. In the reference made to the writer's results[1] a maximum permeability of over 60,000 is shown for both unalloyed iron (deoxidized with 0.15 per cent silicon) and for iron-silicon alloys containing from 3 to 4 per cent silicon, both having a coercive force of 0.08 and a hysteresis loss of 280 ergs for $B = 10{,}000$. This would correspond to less than 1 erg for $B = 100$ (instead of 20 as given in table I of the paper).

The author points out that one kind of strain not to be relieved by annealing is the strain due to nonmetallic chemical impurities; consequently, in order to attain the highest magnetic permeability and the lowest hysteresis loss, it is necessary to reduce these impurities to the lowest possible value. Since 1924, when the writer published his results[2] on iron-silicon alloys, he has repeatedly advocated the hypothesis,

based on experimental evidence, that the magnetic properties of iron for low and medium flux densities are largely a function of the nonmetallic impurities, due to the lattice strains produced by them, so that with no impurities present a single crystal of iron should show infinite permeability and zero hysteresis loss. When P. P. Cioffi published his results[3,4] on hydrogen treated iron in 1930 and 1932, he proposed that the great improvements obtained by him by hydrogen annealing at high temperatures were due to absorbed hydrogen.

In discussing Cioffi's paper at a meeting of the American Physical Society in Schenectady in 1931 the writer contended that the improvement was due to purification.[4] This view, also expressed by Ruder, has since been confirmed and now is generally accepted. Since it seems reasonable to suppose that the persistent advocacy of this view has been influential in the development of magnetic materials during the past 10 or 15 years, it may not be amiss to record the above facts for the historical interest they may have.

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K. M. Lederer (Weston Electrical Instrument Corp., Newark, N. J.): It has been mentioned that permanent magnetism is accompanied by internal tensions and stresses in the material of the magnet. In connection with these statements the writer wishes to refer to an observation made approximately 8 years ago in the laboratories of the company with which he is associated. At that time the writer had a 35 per cent *U*-shaped cast cobalt magnet. This magnet was used as a secondary standard, and in order to preserve its magnetism a keeper was placed between its poles. The keeper fitted snugly between the parallel poles of the magnet, and no clearance between keeper and magnet was noticeable.

One day it was noticed that the strength of the magnet had diminished to the extent of from 15 per cent to 20 per cent, but after recharging, the magnet was brought again almost to its full strength. An examination under the microscope indicated that a minute crack had developed on the inside of one of the bends. Several days later the magnet again was used, and it was then observed that its magnetic strength had diminished to approximately $^1/_2$ its original value. A recharging of the magnet brought back only about 65 per cent of its original value. It was noticed also that the crack had increased in size slightly. The magnet then was set aside for another week or so. At the end of this idle period it was found that almost all of the magnetism was gone, and no amount of recharging would restore it. It was then noticed that the magnet was cracked almost halfway through, and several smaller cracks had developed in the meantime. The conclusion was drawn that there must have occurred an entire rearrangement of the molecular structure, which was effected by the release of internal stresses by the cracks in the magnet.

This observation might be considered as a fair illustration of the theory that permanent magnetism depends on internal stresses in the magnetic material, and in a practical way it will serve as a hint for the design of these magnets and their inspection.

R. M. Bozorth: Knowledge of magnetic domains is still quite limited. As stated in the paper, their volumes can be estimated, but there is less definite information concerning their shapes. Although represented as cubes in the figures, it must not be supposed that they are cubical in form. They are more likely to be considerably longer than they are wide. It can hardly be doubted, however, that a single crystal having homogeneous structure, in the usual sense, contains many magnetic domains, particularly in view of the powder pattern of figure 9 of the paper, which refers to a portion of a single crystal. Theoretical considerations indicate that there is a transition region between domains, in which the atoms are not arranged parallel to either domain, and that this transition region is about 30 atom diameters wide. Thus, it is reasonable to suppose that increasing the applied field will tend to orient these atoms so that they will be more nearly parallel to the field and to one of the adjacent domains. This is equivalent to a shift of the boundary as shown in figure 12 of the paper. So far, this qualitative picture is the best available.

At present there is no very detailed explanation for "drift of permeability." A general discussion is in Ewing's book[1] but the theory has not progressed much beyond this point. At the present time it would seem to be appropriate to attack this problem from the point of view of internal strains due to chemical precipitation or magnetostriction, since some experiments have indicated that pure iron "ages" to a lesser extent than iron containing considerable amounts of impurities. What has been called drift of permeability may be caused by changes in slight internal strains in much the same way that the aging of permanent magnets is caused by the relief of the larger internal strains produced by precipitation hardening.

The idea that the chemical purification of iron tends to increase its permeability is not new. One of the first workers in this field was Gumlich,[2] who investigated the effect of purification and vacuum melting as early as 1908. More extensive and successful work was carried on by Yensen, who in one experiment raised the maximum permeability of iron to 61,000. The more recent work of Cioffi deserves particular emphasis now because his results have led to record values of the magnetic constants which are readily reproduced. In his report at a meeting of the American Physical Society at Schenectady in 1931 Cioffi[3] interpreted his results in terms of chemical purification. An excellent review of the work done in this field is given in a recent book.[4]

In table I of the paper, the 1915 value for the maximum permeability of iron was taken as 45,000. This value was obtained by Yensen[5] for a single specimen. At the same time he also reported 66,000 for another specimen containing 0.15 per cent silicon. These data must be reconciled with the fact that in 1928 Yensen published a curve indicating that in 1920 the highest permeability anyone had obtained in iron was 25,000.[6]

The coercive force of 0.08 mentioned in Yensen's discussion was obtained for $B_{max.} = 10{,}000$, and therefore would have been higher if the material had been magnetized to saturation. The hysteresis loss he quotes of 1 erg for $B = 100$ apparently has been obtained by extrapolation from the value of 280 ergs at $B = 10{,}000$ using Steinmetz's 1.6 power law; it is well known that such extrapolation is not at all valid to such small values of B.

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Permanent Magnet Materials

Discussion of a paper by C. S. Williams published in the January 1936 issue, pages 19–23, and presented for oral discussion at the magnetic materials session of the winter convention, New York, N. Y., January 29, 1936.

R. C. Taylor (Western Union Telegraph Co., New York, N. Y.): It may be worth while to call attention to an important phenomenon that is particularly prominent in some silicon steels, and which may seriously affect magnetic measurements. The permeability and losses of silicon steels at low inductions, such as are used in communication equipment, are not constant but change slowly as a function of the time elapsed after a mechanical or electrical shock. This drift may be large, exceeding 30 per cent in a day under some conditions.

A number of experiments have been made that tend to show the general nature of the effect. These experiments were made with an a-c bridge of the conventional resonance type. The sample with its test winding was subjected to the type of shock being studied, either mechanical shock, such as a blow with a hammer, or electrical shock, such as a large current or a demagnetizing process. The bridge then was balanced as soon as possible and kept in balance as the constants

of the sample changed. It was found that the data plotted as inductance and equivalent series iron resistance versus the logarithm of the time elapsed since the shock gave straight lines within the experimental error of the measurements; that is, the inductance and iron resistance tend to follow a simple law of the type $x = 1 - K \log t$.

It may be seen that if the law were valid for all values of t the inductance and resistance would range from plus infinity to minus infinity, which suggests that this law is valid only for restricted values of time. The conditions are such that the greater part of the drift occurs during a period of a few hours, and subsequent changes, although still in agreement with the law, are quite small in magnitude.

The following general behavior has been observed:

1. The drift decreases with increase in magnetizing force, disappearing near the point of maximum permeability.

2. The drift is greater with the measuring current removed between measurements than when the measuring current is uninterrupted.

3. Various specimens of high silicon steel drift in varying degree at the same magnetizing force.

4. The drift decreases if the temperature of the specimen is increased.

5. The drift changes only slightly with frequency.

6. The iron loss resistance drifts faster than does the inductance.

This phenomenon evidently is capable of making trouble in some cases where sharply resonant circuits are used and in low flux density measurements which may be reflected in later designs. It would be interesting to measure the conductivity of the specimen while its permeability is changing.

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O. E. Romig (nonmember; American Sheet and Tin Plate Co., Pittsburgh, Pa.): A metallurgist working on the production of magnetic materials, finds himself depending on the electrical engineer to show him what is desired, and he must ask both the engineer and the physicist for aid and advice as to fundamentals in order to produce the desired materials.

Metallurgists have been accustomed to producing materials according to physical specifications of ultimate and yield strength, ductility, and related properties. They are familiar with corrosion and welding problems, with production of steels of a specific grain size, and they have surrounded themselves with suitable tools and instruments to help in the solution of such problems. But when the desired properties of a material depend on so fundamental a property as the nature of electron spins and delicate magnetic measurements of quality, scarcely evident by any other means, it is not surprising that many metallurgists and production men are astonished.

However, thanks to the broadening of contacts with technicians from related engineering fields, publication and discussion of ideas such as those expressed in this, and other papers, the metallurgist and production man now are obtaining a clearer idea of why things happen as they do.

The electrical engineer expresses his desires, offers ideas and suggestions that serve as a basis for the research or experimental work necessary to produce these desired materials. New products are developed, or old ones improved, and with the co-operation of the electrical engineer and physicist, the best commercial application is found more quickly.

Since production quantities must be manufactured before costs and practicability can be determined, many products of the laboratory do not become practical on a commercial scale. Before commercially successful materials are obtained, quite often a considerable quantity of expensive alloys unsuitable for other purposes are shown by final magnetic tests to be nearly worthless for the desired product. Unfortunately, in many cases they cannot be reclaimed or used for another purpose. Thus, commercial development of new or improved magnetic materials often is slow and expensive.

The development of a more accurate, theoretical knowledge of the fundamental properties of magnetic alloys, however, helps to make commercial development easier and less expensive. There has been far too much mystery in the past art, with experimental work being done on a "cut and try" basis.

It is believed that progress will continue more rapidly as fundamental knowledge increases; old materials will continue to improve, and new materials may be developed. A vast amount of intensive work always appears on the horizon for those engaged in this development program and the part played by symposia of this character in coordinating the efforts of producers and users of magnetic materials is very great.

H. T. Faus (General Electric Co., West Lynn, Mass.): Although, as shown by the author, the cost of the materials in nickel-aluminum magnet alloy is less than the cost of the materials in chromium magnet steel per unit of magnetic performance, the difficulty of producing the nickel-aluminum alloy may make its cost higher per unit of magnetic performance than that of chromium steel. Hence, the substitution of nickel-aluminum alloy for chromium steel may not be economically justified unless the accompanying dimensional change in the magnet affects other features of the design so as to reduce their cost sufficiently to offset the increased cost of the permanent magnet material.

Perhaps the most interesting field for the new permanent magnet materials is their application to equipment in which the older permanent magnet materials could not have been used at all, because of space and weight limitations.

A permanent magnet material that deserves mention in connection with this discussion is the silver-manganese-aluminum alloy described by H. H. Potter (see "Some Magnetic Alloys and Their Properties," H. H. Potter, *Phil. Mag.*, v. 12, ser. 7, Aug. 1931, p. 255–64). This material has the highest coercive force of any permanent magnet material (5,000 oersteds or more). The maximum magnetic energy per unit volume as given by Potter is somewhat higher than that of 36 per cent cobalt steel. This value has been approached, but not equalled, by samples of this alloy made in the laboratories of the company with which the writer is associated. The high coercive force and low residual induction of this material make it possible to magnetize a thin sheet of it in the direction of its thickness. Such a magnetized sheet of this alloy is an efficient magnet, although its residual induction is so low that strong mechanical forces can be developed only by using it in conjunction with a strong magnetic field. Its mechanical properties are excellent, for it is malleable, ductile, and machineable.

W. C. Jones (Bell Telephone Laboratories, Inc., New York, N. Y.): This interesting paper on the recent developments in permanent magnet materials is most timely in view of the outstanding advance in this field during recent years. The writer would like to comment briefly on this paper from the standpoint of one interested in the design of telephone instruments of which minimum size and weight and maximum stability are important requirements.

For years the choice of materials for permanent magnets was limited to steels having coercive forces of from 40 to 70 oersteds and maximum energy products of 1.0 to 2.5×10^5. Tungsten steel is a typical example of this class. Fairly satisfactory results could be obtained with these materials if considerable latitude was allowed from the standpoints of size and weight, and if the stability requirements were not too severe. However, when the space available for the magnet was limited, and when it was necessary to keep the weight to a minimum, it often proved difficult to design a magnet that would develop the desired amount of useful flux and at the same time meet the size and weight requirements. Furthermore, even when these requirements were met, toe magnetomotive force available to resist demagnetization in many cases was so low that a substantial reduction in flux occurred under the demagnetizing conditions encountered in the use of the magnet.

The introduction of 35 per cent cobalt steel materially improved this situation. This material has a coercive force of about 250 oersteds and a maximum energy product of the order of 8.5×10^5 and made it possible to develop the desired amount of useful flux with a substantial reduction in size and weight and at the same time secure a much more stable magnet. However, the decrease in size was in general not so large as the increase in maximum energy product would indicate for it seldom has proved feasible to effect a reduction of more than $^1/_2$ in the size of the magnet, whereas a recuction of $^2/_3$ to $^3/_4$ might be expected from the increase in energy product alone. In this connection it should be remembered that, although the maximum energy product affords a useful criterion for comparing the inherent properties of various magnet materials, it cannot be relied upon to give an accurate measure of the relative sizes of magnets made from these materials. This is due primarily to the fact that a considerable amount of material must be added in

each case to provide for the leakage field, and that this material, whether added as a leakage sleeve or as a general increase in the cross section, varies with the size and shape of the magnet. Because of the high cobalt content, cobalt steel is relatively expensive. Seldom has the reduction in the size of magnets made from this material been sufficiently large to offset the higher cost; however, there have been many instances in which the increase in cost could be justified by the resultant reduction in size and weight.

The new cobalt oxide, aluminum nickel iron, and cobalt molybdenum alloys have magnetic properties that promise to reduce the cost of the material entering the magnet. The indications are that the maximum energy products of all these materials are of the same order of magnitude, but that the magnetizing forces and flux densities at the maximum product are different. It has been established that the cobalt molybdenum alloy can be substituted for 35 per cent cobalt steel with no major change in the design of the rest of the structure, and that magnets of cobalt oxide and aluminum nickel iron should be shorter and of larger cross section. These characteristics favor the use of straight bars, and hence tend to make possible certain economies due to the simplification of the operations involved in the preparation of the magnet. There are certain types of magnetic circuits, however, in which the shortness of the magnet may in itself be a disadvantage.

It would have been of considerable assistance to the reader if the author had included product curves for the materials under discussion in addition to the magnetization curves. If the writer has interpreted figures 2 and 3 of the paper correctly, the relative lengths and cross sections of the magnets are based on the magnetizing force and flux density corresponding to the maximum product. As already pointed out, this assumption is an optimistic one and may result in misleading conclusions. This comment applies also to the relative weights given in figure 4 of the paper.

It appears that the relative costs given in figure 5 of the paper are based on the quantity of material required to give the same maximum energy product. As already pointed out, this is an ideal seldom realized in practice. Furthermore, as Williams states, these costs do not afford a measure of the expenditures involved in the preparation of the magnet. In many cases it is these expenditures that determine the material finally chosen for use in a magnet. This is particularly true when, as in the case of cobalt oxide and cobalt molybdenum steel, the physical characteristics of the material limit the methods employed in the preparation of the magnet.

Another factor of importance in the use of the high coercive force materials is the matter of magnetization. Much higher magnetizing forces are required than were necessary for materials having lower coercive forces. Furthermore, magnets made from these materials are in general shorter and more open; hence, they must be magnetized with the external circuit in place if the most economical use is to be made of the magnet material. Localizing a high magnetizing force at the magnet of ten becomes a problem. Even for the more complicated forms of 35 per cent cobalt steel magnets it has been necessary in a number of instances to use a coil wound around the magnet for magnetization. Such methods are expensive.

The practical use of the materials covered by this paper depends to a considerable extent on the successful solution of the problems of fabrication and treatment mentioned in the last paragraph. The importance of work along these lines cannot be overemphasized.

K. M. Lederer (Weston Electrical Instrument Corp., Newark, N. J.): The writer is aware of the demand for more sensitive instruments, and it is understood tacitly that the discoveries of K. Nishima relative to aluminum-iron-nickel magnets aroused his deepest interest in 1932. The writer not only carried on some research work on his part as soon as the first publications of Mishima's work were available, but also tried to obtain sample magnets from domestic and foreign makers wherever they were available. The coercive force values agreed but none of the samples obtainable approached the residual induction values found in the literature. In fact, a residual induction of somewhat more than 4,000 gausses represented a fair average, and 5,500 gausses almost the maximum. The writer would like to learn from C. S. Williams whether the values referred to by him represent laboratory samples or commercial products. If they are commercial products, the writer would be materially interested in learning whether such magnets are available on the open market.

The literature also contains some contradicting statements in reference to the magnetizing forces for the aluminum-iron-nickel magnets, varying from 1,000 to 10,000 oersteds. It would, no doubt, be of general interest to hear from C. S. Williams the means and ways of producing these magnetizing forces.

Several of the discussers already have pointed out that in order to make use of these new magnetic materials it will be necessary to redesign the various apparatus utilizing permanent magnets. The general tendency probably will be such that where formerly the permanent magnet enclosed the live parts of the instrument, that is, core, movable coil, and magnet, the future will bring constructions wherein the much shorter magnet will be enclosed by core, and pole pieces.

R. F. Edgar (General Electric Co., Schenectady, N. Y.): This paper on permanent magnet materials is of great interest, for it gives a picture of the rapid progress made in the development of permanent magnet materials in recent years, and presents comparative data on the newly developed materials. Not only have the new materials with their improved properties made possible new and better designs of apparatus employing permanent magnets, but also they have opened up possibilities of new uses for magnets in other apparatus. Permanent magnet materials and their characteristics are of increasing interest to many designers who previously have had little to do with them, and this paper should be helpful to them.

The author has pointed out the value of the maximum energy product as a criterion by which to compare magnet materials and to determine the induction at which the material may be used most efficiently. It would have been desirable, particularly for those who may not be familiar with permanent magnet problems, if the energy product curves could have been incorporated in figure 1 of the paper along with the demagnetization curves. One could then get a little clearer picture of the way in which the energy products compare, the inductions at which they are maximum, and the degree to which the magnet efficiency decreases if the operating induction is other than that for the maximum energy product.

In figures 2, 3, and 4 the author has compared magnets of different lengths and cross sections for the various materials. The writer assumes that each magnet was given the proper length and cross section to permit each of the 6 different materials to operate at the induction and magnetomotive force for which the energy product is a maximum. The writer should like to ask whether any allowance was made in these charts for the effect of leakage flux, or if it was neglected. Materials of high coercive force in some applications may have a slight additional advantage over those of low coercive force, in that the short thick forms offer less surface area from which leakage flux may emanate.

The author's remarks concerning figure 5 of the paper, the relative cost chart are worthy of emphasis. Inasmuch as this is a comparison of material costs only, it may prove misleading if finished magnet costs are to be considered. The differences in design of the magnets and of the associated apparatus may have so great a bearing on the final economic use of the materials as to place them in a different order than that in which they stand when compared on the basis of material costs only.

Magnetic Alloys of Iron, Nickel, and Cobalt

Discussion and author's closure of a paper by G. W. Elmen published in the December 1935 issue, pages 1292–99, and presented for oral discussion at the magnetic materials session of the winter convention, New York, N. Y., January 29, 1936.

J. P. Barton (American Sheet and Tin Plate Co., Pittsburgh, Pa.): The paper by G. W. Elmen is very interesting and comprehensive in revealing the wide range in magnetic characteristics available for various requirements. To obtain the data and curves presented in this paper one might not realize offhand the years of careful work necessary thoroughly to cover the magnetic characteristics when many variables are present. In table I of the paper, up to 3 other elements are shown as alloyed with iron and for each such alloy prepared, and the effect of various heat treatments must be determined to indicate which will be most suitable. For each treatment the magnetization curve, hysteresis loops, saturation flux density, resistivity, incremental permeability, initial permeability, and maximum permeability should be taken in order

to reveal the ability of the alloy sample. All of these factors depend upon the degree of purity of the alloy, its preparation; in short, its intimate history from its conception.

The introduction of these magnetic alloys has assisted greatly the advances and refinements in the various communication fields. Although the use of such alloys is now very small when compared with the silicon steels, their future use undoubtedly will increase.

J. S. Murray (Follansbee Bros. Co., Follansbee, W. Va.): G. W. Elmen's paper is a valuable contribution to a very important subject, especially because information of this nature concerning alloys of iron, nickel, and cobalt is so very meagre. The paper is interesting also because of the vast amount of research work involved and the very definite conclusions regarding the proper applications and usefulness of the different alloys in the communication field.

It is also interesting to note that the author concludes that the uses of silicon steel still have a very important part in the communication apparatus picture. The writer believes that this situation will continue, because silicon steel manufacturers are cooperating very closely with the electrical manufacturers in exchanging ideas, with the result that improved and more satisfactory products are being continually developed for this class of work.

T. D. Yensen (Westinghouse Elec. and Mfg. Co., East Pittsburgh, Pa.): This paper is an excellent review of the good work done at the Bell Telephone Laboratories on iron, nickel, and cobalt alloys. It is unfortunate, however, that the author should not have made an effort to cover the subject more broadly. As Elmen has restricted his paper to the work done at the Bell Laboratories, the writer should like to supplement it by calling attention to a few items that should not be overlooked.

The magnetic properties of the iron-nickel alloys were first systematically investigated by Burgess and Aston at the University of Wisconsin prior to 1910.[1] Their chief contribution was to show in a general way that the saturation value dropped with increasing nickel content up to about 30 per cent nickel and then gradually increased again, reaching a maximum at about 50 per cent nickel. They also pointed out that alloys above 30 per cent nickel have a higher initial permeability than the unalloyed iron used for comparison.

On the basis of these results and others obtained at the Westinghouse laboratories between 1910 and 1915, L. W. Chubb in 1915 applied for a patent on the use of iron-nickel alloys in the construction of current transformers,[2] in which high permeability at low induction is of paramount importance.

In 1915, the writer started work on the iron-nickel alloys at the University of Illinois and continued it at the Westinghouse laboratories after 1916. The first results were published in 1920,[3] showing possibilities of greatly improved magnetic properties at low flux densities for alloys above 30 per cent nickel, particularly in the region of from 50 to 70 per cent nickel, in which region the alloys are markedly susceptible to mechanical and heat treatments and to other alloying elements. The work was continued, culminating in the discovery of the remarkable alloy "Hipernik" in 1924,[4,5] containing from 40 to 60 per cent nickel, and having a very high permeability at low and medium flux densities and very low hysteresis loss. "Hipernik" in the form of sheets and strip from 0.005 inch to 0.014 inch thick has been produced commercially during the past 12 years with permeabilities above 100,000 and with losses of less than 0.30 watt per pound for $B = 10{,}000$ and a frequency of 60 cycles per second. Permeabilities of over 150,000 and losses less than 0.26 watt per pound have frequently been obtained in commercial lots.[6]

The patented process for producing "Hipernik" consists of annealing in hydrogen at high temperatures. It is a purifying process and is distinctly different from the process developed at the Bell Laboratories that resulted in permalloy.

The name permalloy originally was applied to the alloys containing about $78^1/_2$ per cent nickel that responded to a particular heat treatment consisting of cooling rapidly from the magnetic transformation point. It was found that alloys containing between 60 per cent and 90 per cent nickel responded to this treatment to an increasing extent as the nickel content approached $78^1/_2$ per cent. Alloys containing less than 60 per cent nickel, however, are not appreciably affected by this treatment and the Bell Laboratories have, so far as the writer knows, made no contribution to the art of improving the magnetic properties of the iron-nickel alloys containing less than 60 per cent nickel. The alloy 45 permalloy as described by Elmen has a maximum permeability of about 23,000 and an initial permeability of about 2,700—values that are not appreciably better than some published in 1920,[3] and is therefore not an improved alloy. From an examination of the values given in table III of the paper for 45 permalloy, it seems to the writer that the material must have been produced by the "hipernik" process.

The first item in table III of the paper should have been called "hydrogen treated 'Armco' iron," or better still, "99.99 per cent iron," because after the purifying treatment the material no longer possesses the characteristics of "Armco" iron.

References

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G. W. Elmen: In closing the discussion of this paper, the author would like to go back for a moment to 1913, when he began has magnetic studies of the iron-nickel alloys, to contrast the positions occupied at that time by the art of electrical communication on the one hand, and that of power, light, and traction, on the other. In communication, engineers were concerned with the phenomena of very feeble currents and weak magnetic fields, for which the initial permeability was their chief concern. On the contrary, the power industry was concerned with high voltages and large currents, involving strong magnetic fields under which the behavior of magnetic materials at flux densities approaching saturation was fundamental. It was natural that these contrasting arts should explore magnetic materials from opposite viewpoints, and it was inevitable that they finally should merge into fields of common interest. Both groups of investigators published their findings as promptly as possible for the benefit of their engineering colleagues. This paper attempted only to summarize those developments arising from telephonic researches, and were of particular value to the art of electrical communication.

Prominent investigations from the power side were those of Chubb and Yensen of the Westinghouse organization and the earlier academic studies of Burgess and Aston. Yensen started his painstaking series of investigations in the same decade as did the author, but with the point of view of electric power engineers, as is evident from his published reports. For example, he prefaced his 1920 paper with the statement: "This investigation was undertaken to determine whether any iron-nickel alloys could be found having a higher saturation value than pure iron." In summarizing this investigation of nickel-iron alloys he wrote: "(Only in the region from 50 to 70 per cent nickel are the alloys markedly susceptible to mechanical and heat treatment and to other alloying elements,) and in this region there is much uncertainty as to the magnetic properties at low flux densities." This sentence, of which only the portion in parentheses is quoted in his discussion of this paper, implies a lack of interest in the behavior of iron in the region of low flux density, and indicates the prevailing ignorance of the properties of these alloys in the range of flux densities important to communication equipment.

He now appears interested in extending the discussion of the subject of this paper beyond the intention as stated in its introduction—an extension the author considered unnecessary, because another paper ("Present Status of Ferromagnetic Theory," R. M. Bozorth, Elec. Engg., v. 54, Nov. 1935, p. 1251–61) at the same session reported the major advances in magnetic materials during the last 20 years. However, since he has raised certain questions of priority in the development of this field, the author is compelled to give his point of view concerning them.

Considering in detail Yensen's discussion, his reference to the work of Burgess and Aston at the University of Wisconsin requires some comment. They reported no measurements made at field strengths less than 10 oersteds. The lack of knowledge of the low flux density behavior of these alloys in 1915 was further indicated when Chubb endorsed alloys of from 33 to 35 per cent nickel for the cores of current transformers, because, he said, their magnetization curves lacked inflection at the origin. Of course it is known now

that this inflection is characteristic of all nickel-iron alloys.

In the author's own work, which dates back to 1913, it was observed that heat treated 70-30 nickel-iron was much superior to iron and silicon steel at the low field strengths in which he was especially interested. Based on extensive tests, the effects of composition, heat, and mechanical treatment were surveyed, and patents were applied for in 1916, subsequently covering alloys having superior properties at the low flux densities useful in communication apparatus.[1] A brief survey of the low flux density behavior of the nickel-iron alloys and more detailed information on the most outstanding composition were published in 1923.[2] In that article, the importance of low flux density behavior for communication apparatus was pointed out, and a set of permeability curves was given for magnetizing forces ranging up to 0.07 oersted, in contrast to the preoccupation of other investigators with medium and high flux density behavior.

As early as 1916, steps were taken to use some of these alloys in communication circuits, and as mentioned in the paper under discussion, a submarine telegraph cable continuously loaded with 78.5 permalloy was laid between New York and the Azores in 1924. Certain telephone relays and repeating coils using 45 permalloy already were under test in 1923, and they were advanced to large scale production as fast as was commercially feasible.

That disclosure of the remarkable properties of these alloys turned the attention of other investigators to the low flux density region, and it led to many diligent attempts to find substitute alloys possessing these properties, and to discover further improvements in the nickel-iron alloys themselves.

The improvement described by Yensen in 1925 consisted of employing hydrogen annealing (already well established for magnetic materials[3,4,5] in the preparation of alloys containing approximately equal proportions of nickel and iron. In the paper under discussion there was no intention of disparaging that improvement, but it seemed unnecessary to single it out for special description, since hydrogen annealing increases the permeability of most magnetic materials, as was indicated in table III of the paper.

Yensen tends to belittle the contribution of the Bell Laboratories to the art of improving the magnetic properties of nickel-iron alloys containing less than 60 per cent nickel. He points to the initial permeability of 2,700 and maximum permeability of 23,000 quoted for standard pot annealed 45 permalloy as "values that are not appreciably better than some published in 1920." The article referred to, published by him, gives no data whatsoever on initial permeability, and it gives maximum permeabilities ranging from 3,200 to 9,600 for alloys of 50 per cent nickel content, the nearest composition to the present 45 permalloy. With special purifying processes, permeabilities as quoted in table III of the paper are obtained. Those figures speak for themselves.

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High Power Audio Transformers

Discussion and author's closure of a paper by J. F. Peters published in the January 1936 issue, pages 34–36, and presented for oral discussion at the magnetic materials session of the winter convention, New York, N. Y., January 29, 1936.

J. S. Murray (Follansbee Bros. Co., Follansbee, W. Va.): The paper by J. F. Peters is very interesting, especially since it outlines clearly, among other things, the important requirements of core material for such apparatus as high power audio transformers, in which a wide range of frequencies and full output at any one frequency or combination of frequencies is essential. Generally speaking, it is most gratifying to the writer that such fine papers on magnetic materials have been presented, and that this important subject has been given such a prominent place in the activities of the Institute.

True McLean (Cornell University, Ithaca, N. Y.): J. F. Peters has stated that large audio transformers differ from 60 cycle power transformers principally in the greater ratios of iron to copper weights generally employed. Leakage reactance and distributed capacitance of the winding are given as factors limiting the winding turns, and with the turns so limited, the core areas must be increased to meet necessary requirements of minimum open circuit inductance.

The process of increasing the band width of uniform transmission by increasing the iron to copper weight ratio cannot be continued indefinitely. For any given set of external performance requirements and winding turns, 2 factors tend to limit the minimum core area that may be used. In the first place, the flux density must remain below a certain value that is determined by the tolerable harmonic percentage introduced by the magnetizing current, which is not linear with respect to voltage. In the second place, as Peters has said, the open circuit inductance must be large enough to keep the frequency discrimination effect within prescribed limits at the lowest frequency. These 2 considerations each determine a minimum core area. In general the 2 limiting areas are not the same, and the design is made to satisfy both conditions by building to the larger area.

The factors of area and winding turns do not enter the familiar formulas for inductance and maximum flux density in the same degree. It is possible, therefore, to set up equations for turns and area in terms of a number of external requirements and the effective a-c permeability of the core. A balanced design may be reached in which the limitations of core area due to both conditions are reached together. Peters implies that inductance was the limitation in the larger transformers, but he does not say so directly. If a balanced design is used, the equations indicate that the permeability must increase in proportion to the area of core to preserve the balance. In smaller units this makes worth while the use of high permeability core materials to save space and weight. In large units the design may be unbalanced with regard to the 2 foregoing limitations because of the relatively high cost of alloy core material.

In the output transformers an air gap is used to prevent partial saturation of the iron due to unbalanced plate currents. This seriously lowers the effective design permeability, and it would seem worth while to use some means, such as a differential bias adjustment, to force a balance. This should be easier to do in the case of a 4 tube combination than with a 2 tube arrangement. The pair of tubes on one side of the combination may be made up of the highest and lowest current tubes of the 4, tending to improve the balance. A comparatively small unbalance not only affects the transformer core adversely, but also causes the introduction of even harmonic components in the output, even if the transformer is not seriously magnetized.

The leakage reactance may be lowered without reducing the winding turns by the well-known methods of interleaving the windings in sections. This method is criticized because it tends to increase the winding capacitances, but it must be noted that in large designs the impedances between which the transformer works are relatively low. For the transformer under discussion the effective load resistance connected to the secondary is only about 100 ohms. This makes the effective plate to plate load impedance offered to the tube combination only about 1,160 ohms. The presence of capacitance in the primary winding tends to reduce the voltage drop caused by leakage reactance, and if not excessive, actually improves the performance at the highest frequencies. With impedances as low as those under discussion, the winding capacitances may be as high as about 0.01 microfarad effective, plate-to-plate, without causing trouble.

Peters says that the regulation of the third and fourth stage transformers was arbitrarily divided. It is difficult to see how the driver transformer can have any appreciable reactance drop because of the nature of the connected load. At low modulation percentages the transformer is effectively open circuited at the secondary, since it merely supplies control grid voltage. At higher modulation percentages the grid currents of the output tubes may become quite large, but may not be regular because of high secondary electron emission from the grids. It is entirely possible to have negative regulation, and unless the leakage reactance of the driver transformer is very low, the grid currents may cause very severe harmonic distortion.

The author remarks that performance tests were not made on individual units, but over-all measurements indicated satisfac-

tory performance of the entire assembly. It is well known that input transformers may be tuned to give exaggerated response at the upper end of the frequency range, and thereby cover up the deficiencies of regulation in the output transformer. This takes care of the amplitude distortion, but does not affect the phase angle of the load impedance offered the modulator tubes. Reactance in the output transformer produces an appreciable phase angle that makes the modulator tubes overload at signal levels lower than the overload point for a pure resistance load. Since this occurs only at the highest frequencies, it is not apparent as audio distortion that may be detected by ear, but it contributes seriously to the radiation of components of frequency that interfere with other stations operating on adjacent channels.

J. P. Barton (American Sheet and Tin Plate Co., Pittsburgh, Pa.): The pape by J. F. Peters is very interesting in showing how the small audio transformer of about 10 years ago has developed in size, through careful design, to handle kilowatts instead of milliwatts, over a wide frequency range. Of particular interest is the fact that more than 95 per cent of the weight of the 180 kilowatt unit is in the core, which apparently is assembled from the best grade of transformer silicon steel. It is evident that the ratio of iron to copper weights, as well as the total weight, must increase materially as the power capacity of the transformer increases. The number of turns must decrease if the same frequency range is to be maintained, because of the restricted values of distributed capacitance and leakage reactance. If the core is not to be too large, the best core material should be used, not only for high permeability but for low core loss.

Because magnetic materials are playing an increasingly important part in electrical engineering, it is desirable that consideration be given to holding similar symposia at future conventions.

J. F. Peters: True McLean's comments concerning increasing ratio of iron section and winding turns indefinitely are correct, but within the frequency range involved it appears to constitute the most practical way of meeting the conditions. There are 2 alternatives: (1) higher permeability core material allowing an appreciably higher flux density, which is not practical at the present state of the art, and (2) interlacing of windings, which results in coils that have poor mechanical properties, unless they are wound one on the other, and then the electrostatic capacitance between them becomes high.

The author does not wish to infer that the units described in the paper constitute results of the only satisfactory way of building audio transformers.

The statement in the paper that over-all measurements indicated satisfactory performance was not based on audibility tests, but by measurements. The harmonic distortion factors based on root-mean-square values were 4 per cent at 90 per cent modulation, $2^1/_2$ per cent at 70 per cent modulation and approximately 1 per cent at 5 per cent modulation.

Supervisory Control and Remote Metering

Discussion of a paper by J. V. B. Duer published in the January 1936 issue, pages 70–75, and presented for oral discussion at the automatic stations session of the winter convention, New York, N. Y., January 29, 1936.

A. E. Anderson (General Electric Co., Philadelphia, Pa.): Often supervisory control and indication are considered in terms of central station application. J. V. B. Duer has called attention to the application of this type of equipment to a main line electrification, such as on the Pennsylvania Railroad, where on a heavily traveled section hundreds of trains are in daily operation. The extent of this application serves to indicate the dependence that has been placed on the reliability of operation.

Supervisory control has been applied over a period of approximately 15 years, and in this time has demonstrated its flexibility of application and dependability of operation. A recent application to a major railroad system, such as described by Duer, demonstrates that this type of equipment has been able to meet the more exacting demands that have arisen as the field has expanded.

In addition to this type of application, entire city railway systems are controlled from a central point. An outstanding example of this type of system is located in New York City. Ultimately it will control approximately 125 mercury arc rectifiers and synchronous converters, 200 ventilating fans, and 800 feeder and track circuit breakers, in addition to providing voltage indication, current readings, and other essential information.

In such extensive systems it is desirable to set up zones, each having a number of substations and feeder circuits. The advantages of such an arrangement are independent operation of each group, which reduces the average time of operation, and in case of line wire failure only the interruption of operation of a small portion of the system. quite often these zones are in several directions from the central point, thereby forming a compact group; however, in applying this type of equipment to a railroad, the associated line wires usually will be found to follow the right of way, which, as a rule, proceeds in one direction. In zoning a system of this kind it will be necessary to group the substations on different line wires, with the result that the line wires to the more remote substations overlap those to the nearby substations.

A unique feature in the installation mentioned in Duer's paper is the use of a pair of spare wires that extend to the remote substation, and arranging the control so that the power dispatcher is able to transfer the spare line wires automatically to any one of the substations, thus minimizing the probability of interruption of the supervisory control equipment due to faulty or damaged line wires. This transfer can be made prior or subsequent to a line wire failure.

Supervisory control and remote metering permit power dispatching duties to be grouped at a central point, and by means of suitable indication may give the power dispatcher a system that responds quickly to the various changes and acquaints him of those changes with a minimum amount of delay and confusion. The relation of any individual operation to the balance of the system may be quickly determined.

As power systems continue to expand, it becomes desirable to have centralized control and indication, together with remote metering. Such requirements are met readily by the modern designs of supervisory control and remote metering systems, as illustrated by Duer's paper.

Improvements in Communication Transformers

Discussion and authors' closure of a paper by A. G. Ganz and A. G. Laird published in the December 1935 issue, pages 1367–73, and presented for oral discussion at the magnetic materials session of the winter convention, New York, N. Y., January 29, 1936.

F. C. Young (Stromberg-Carlson Telephone Mfg. Co., Rochester, N. Y.): When making the modulation measurements, how was a pure input signal obtained at 30 cycles per second? Filter elements having a high Q and not producing modulation are difficult to obtain. The writer presumes that the value of modulation components 80 decibels below the fundamental applies to this low frequency.

The writer has noticed that the substitution of a high permeability core for one of silicon steel in a given winding, in a magnetically shielded input transformer of an a-c operated amplifier, results in less pickup into this transformer, when the transformer is oriented for minimum pickup. What is the explanation of this phenomenon?

The writer has found that core type transformers are less susceptible to stray fields than shell type transformers, the difference in pickup being a function of the positions of the transformers with respect to the field; however, it has not been found possible, in general, to eliminate magnetic shielding. Is this the experience of the authors?

The writer has found that some transformers exhibit an increase in transmission at frequencies higher than those at which a minimum is experienced due to leakage reactance. This is not explained by the T diagrams used by Casper. The writer has not noticed this effect mentioned before and is interested in any explanation the authors may have.

A. G. Ganz and **A. G. Laird:** In reply to F. C. Young, the modulation measurements, with the exception of some at 60 cycles per second, were made with vacuum tube oscillators and filters. Filter elements of low modulation and requisite Q for low frequency measurements are expensive and bulky, but otherwise not difficult to make. Modulation components 80 decibels below a fundamental of 35 cycles per second are obtained in certain low level input transformer and repeating coils.

The authors have observed effects similar to those described by Young in shell type input transformers placed in numer-

ous positions with respect to an external disturbing field. The explanation of this phenomenon lies in the relative distortion of the disturbing field pattern in the transformer due to the self-shielding effect or reaction of the windings.

With regard to core type transformers, it has also been the authors' experience that supplementing magnetic shielding is necessary with their use.

Irregularities in the transmission above the nominal transmitting frequency range such as Young observed frequently are found in both input and output transformers. Such irregularities generally are due to secondary resonance effects arising from the sectionalizing of windings. For this reason considerable skill in design is required to eliminate them in those cases where their presence would be detrimental to the proper functioning of the transformer. In many cases the capacitances between windings play a significant part.

Remote Metering and Automatic Load Control

Discussion and author's closure of a paper by J. T. Logan published in the January 1936 issue, pages 40–47, and presented for oral discussion at the automatic stations session of the winter convention, New York, N. Y., January 29, 1936.

Robert Treat (General Electric Co., Schenectady, N. Y.): As power systems increase in size, and in the number and complexity of their interconnections with other large systems, it becomes increasingly desirable that the load dispatcher should know and be able to control the magnitude of various electrical quantities. Among the most important of these are the kilowatts at strategic points, such as the power over tie lines between systems.

Experiences of the past few years have indicated more clearly than ever before the necessity of making the maximum effective use of all available facilities, because unused or partly used facilities represent investment employed inefficiently. The author is not the only operator who has found it difficult or almost impossible to use tie line facilities effectively where the load swings reach a value that may be a large proportion of the rating of the line.

Several years ago it became apparent that a closer control of frequency was a necessary first step in reducing the swings in tie line loads. Systems for the automatic control of frequency were developed, and several of them are in operation; however, it is equally apparent that automatic control of frequency is not a complete solution, and it must be supplemented by automatic load control. There are now in use several methods of controlling tie line loads, of varying degrees of refinement and effectiveness. The author describes an ingenious scheme, developed by him and his associates, that appears to meet the requirements imposed upon his system.

The author has said "too few engineers are familiar with the details of the problems involved." Several questions suggest themselves, and the answers are doubtless clear to the author, even though they were not given in the paper. For example, when the automatic load control is in operation, is there also automatic control of frequency anywhere on the interconnected system on the author's end of the line? If so, is there any tendency for this frequency control to oppose the automatic load control? If this tendency exists, how is it circumvented?

The prevention of important swings in the load over ties between other large systems at times of rapidly changing load, such as during the noon hours, has been found to be difficult. This is because of the difficulty of keeping the necessary increase in generation matched exactly with the increase in load. On a system not interconnected, any discrepancy between load and generation causes a variation in frequency, but on a system connected to another having automatic frequency control this discrepancy is reflected in departures from schedule of the load over the tie. If there is no automatic frequency control on the author's end of the tie line, how are large load changes on the author's system prevented from causing considerable variations in the tie line load? That they are so prevented seems to be substantiated by the charts in the paper, but it is not clear how this is accomplished.

The author and his associates deserve much credit for the development of an ingenious and practical solution of a problem that has vexed system operators in the past, and will in all probability vex them even more in the future, unless adequate remedies are applied. One such remedy is described in the paper.

E. E. George (Tennessee Electric Power Co., Chattanooga): J. T. Logan and his associates have done a good service for the electrical industry in pointing out the necessity of more engineering development in facilities for system operation. In the average power company no group of men has had to bear such inadequate and obsolete facilities as have the load dispatchers. In only a few outstanding cases are load dispatching offices well located, properly lighted, adequately ventilated, equipped with telemetering on all tie lines, or provided with a co-ordinated and universally connecting telephone system. Supervisory control for dispatching frequently is poorly chosen, burdening the dispatcher with too much detail on certain stations, or giving him insufficient control of important stations.

Logan's paper indicates another unsatisfactory condition in the industry. The failure of the manufacturing companies to develop and supply, at a price satisfactory to the customer, certain important operating facilities makes it necessary for operating engineers of the power companies to do much pioneering and development. During the last few years development and application engineers of the manufacturers have been co-ordinated and budgeted by the production and sales executives until they have lost much of the originality and ingenuity that should be encouraged. Perhaps some manufacturer may find a way to put this class of men under the research department, so that they can anticipate customer's needs instead of waiting until the customer needs something in a hurry.

Recently so many restrictions have been thrown upon the expenditure of capital that it is much easier for the utility to have its own employees develop or build equipment than it is to get executive approval for the purchase of complete equipment. It looks as if the manufacturers would have to meet this sort of competition for a long time. The customer may not save money but he can get the job done promptly and with less criticism and argument than if he submits the budget item for his requirements.

The recent activities in centralized dispatching by the electrified railroads and by aviation companies may result in more attention to dispatching facilities. The few power companies that have reasonably adequate operating facilities are those that have encouraged relay engineers and other technically trained men in the operating departments to make technical improvements in facilities and methods for system operation.

The paper clearly states a desirable set of specifications for telemetering. The only one suggesting critical comment is no. 2, which states that impulse methods impose such a severe duty upon relay contacts as to make such a system unreliable or expensive to maintain. Relays such as the types used in high speed telegraph service have been found to stand telemetering duty in properly designed circuits with a minimum of attention or expense. Being jack mounted, such a relay can be replaced instantly in case of trouble. This is another of the many ways in which the power industry can profit by keeping in touch with the experience and facilities of the communication companies.

It is interesting that the Georgia telemetering scheme uses high vacuum tubes, whereas many electronic applications promoted by the manufacturers of power equipment use soft or vapor filled tubes, even where rectification is not involved. Although the vapor filled tube is applicable where the power requirements are heavy, it has very limited application where communication, measurement, or close control of any kind is required. Attempts to promote the use of vapor filled tubes have been an obstacle to the more general use of electronic devices in the power field, particularly in connection with system operation.

Is it possible that certain manufacturers have felt secure in their control of vacuum tube patents and have relied too much on their commercial position and legal rights instead of encouraging technical development and engineering application to meet the customers needs?

In the last 2 or 3 years there has been sufficient complaint from a wide variety of users of electronic equipment to indicate that manufacturers owe their customers much in action, or at least an explanation. The "annual reviews of progress" issued by the large manufacturers do not tell the whole story so long as many users of electronic devices prefer to deal with small and inexperienced manufacturers and so long as so many users are forced to do much of their own development work. The user that assumes a middle course and tries to make use of communication developments for industrial purposes may have better success if he has sufficient patience to get through the labyrinth of commercial policies.

The company with which the writer is associated during the last year was faced with much the same telemetering problem that Logan described. It was solved by an entirely different circuit arrangement that

used high vacuum tubes of the type used in telephone repeaters. A complete description of the new telemetering system first applied in Tennessee is too involved for presentation here, but the channel portion is a standard circuit of the communication companies for voice frequency carrier telegraph service. For 8 months it has been operating satisfactorily without maintenance on a 180 mile telephone line, without interference with the simultaneous normal use of the line. It met the most urgent requirements for telemetering with this carrier telegraph scheme and the company decided to work with one of the manufacturers in developing improved terminal equipment and in trying out other channel frequencies. This work is progressing rapidly and field tests have shown that the problems involved can be solved satisfactorily, and that for some lines a low frequency channel can be used.

Logan's new telemeter has operated very satisfactorily and has effected a remarkable increase in tie line capacity and tie line reliability at all times. Operating conditions have been such that the Georgia Power Company was regulating the tie line load and had regulating capacity at the Tugalo plant.

Much of the effectiveness of telemetering and automatic load control on the Georgia system has been due to fundamental improvements in governor control made by Logan. These possibly are beyond the scope of his paper on electrical equipment, but to many observers these governor improvements seem to be an even greater contribution to system operation than the telemetering facilities described in the paper.

V. M. Marquis (American Gas and Electric Co., New York, N. Y.): Of the scores of remote metering schemes that have been suggested from time to time, and of which some are in operation, relatively few have been applied where long distances are involved. The need for remote metering over long distances, however, has existed for some time, and became particularly clear with the further development of interconnection. The reluctance to adopt it has been due partly to the lack of suitable equipment and partly to the lack of understanding of the benefits to be derived from the use of such equipment. It seems that the carrier current remote metering scheme described by the author offers a practical and economical solution of the problem.

Attention has been directed to the need for this type of equipment with the recognition of the possible improved system performance to be attained by co-ordinating frequency and load control properly. Too frequently adequate metering and control facilities have not been provided. The author is on sound ground when he states that an adequate graphic record of power flow on the line must be furnished the dispatcher if he is to regulate the tie line loading properly. It is generally agreed that an indicating meter is unsatisfactory, and in many cases, where close regulation is being attempted, it may do more harm than good. Often the dispatcher has had to rely mainly on a communication system for the necessary information for regulating a tie line, but this leaves a great deal to be desired. It seems likely, therefore, that the scheme described by the author, or some other equally satisfactory method, will find considerable application on transmission systems as time goes on. It is difficult to say how much telemetering of this type will be required, but it will depend to a large extent on the degree of perfection of the ultimate solution of the load regulating problem. Eventually it may be deemed sufficient to give the dispatcher an accurate graphic record of the power flow and let him maintain tie line loading by adjusting the plant loads, or the record may be sent from the tie line to the regulating plant and its load shifted either manually or automatically. The ideal solution in most cases would be to transmit the tie line load indication to many plants and regulate the load automatically in such a way that the efficiency of any unit or plant is not impaired as a result of large load changes. This would call for an extensive telemetering installation in some cases.

The depression brought out the necessity of placing reduced system loads on the most efficient generating stations and energy exchange with neighboring companies whenever economies could be effected. This has meant interchange over tie lines, and in many cases the desire to load these lines as near to their limit as possible. However, assuming a line to have a capacity of 50,000 kw, it may be safe to rate its capacity at only 25,000 kw, because of normal swings resulting from improper co-ordination of load and generation on either or both sides of the tie line. The results given in table II of the paper show that the rating of a tie line can be increased materially by proper regulation of power flow over it, and that the maximum gain is realized if the line is controlled automatically. The advantage of doing the job automatically is to be expected, for the automatic method means starting to correct as soon as a change in condition starts, although in general with manual control it is necessary to wait until the change is completed. Several similar cases on the system of the company with which the writer is connected have demonstrated the beneficial results of proper load regulation. One case was experienced during the early part of 1932 when a loading schedule was set up on one particular tie line and it was found that the possible savings were reduced several thousand dollars per month because poor tie line regulation made it necessary to take the load variations on a high cost steam plant. Steps then were taken to improve regulation, and with proper regulation practically all of the possible savings were realized as a result of this proper regulation.

In this case, the problem of obtaining power flow records from distant points did not have to be faced, but the advantages to be gained by proper regulation were emphasized forcefully.

One of Logan's remote carrier current metering sets is being installed on an experimental basis on a 104 mile, 132 kv line of the system of the company with which the writer is associated. The installation differs from the author's only in that it will be directly coupled to the 132 kv transmission line instead of telephone lines. In this case 132 kv coupling capacitors already were installed in connection with the carrier current telephone system. The transmitter will be located at Philo and the receiver at the Turner substation, the central dispatching office of the Appalachian Electric Power Company. Normally there is fairly heavy interchange over this tie line between the Appalachian Electric Power Company and The Ohio Power Company, and the direction of power flow normally is reversed during certain periods of the day. The present method of operation is for the Ohio system to control frequency automatically and for the dispatcher at Turner to adjust loading on the Appalachian plants to hold the scheduled load on the tie line. It is difficult, however, for the Turner dispatcher quickly to get a true picture of the interchange between the 2 companies because of a tap about midway between the 2 terminal points. This remote metering should make possible better tie line regulation and reduce the regulating burden of the frequency controlling stations. Later, this installation probably will be used as a means of automatically controlling the tie line from one or more of the Appalachian plants.

It was hoped that the results of this installation could be reported at this time; however, only laboratory test results are available at present. There is no reason why this installation should not function as satisfactorily as the one coupled to the telephone line.

This paper does not specifically discuss frequency control; nevertheless, it should be remembered that frequency and load control really are one and the same problem. Satisfactory operation of large interconnected systems ultimately will be accomplished by the proper co-ordination of frequency and tie line control, and experience indicates the necessity of a combination of frequency and tie line control throughout the interconnected system. To accomplish this, remote metering or control necessarily must play a very important part.

J. T. Logan: Although the paper deals primarily with remote metering and automatic load control, it is interesting how the discussions link tie line load control with frequency control. Incidentally, the apparatus described in this paper was developed as a step toward improvement in frequency control. The closing remarks therefore, will deal with the co-ordination of tie line load control and frequency control.

Robert Treat asks if any attempt is made to regulate frequency on the Georgia or Alabama end of the interconnected systems while the load on the Georgia-Tennessee tie line is being controlled automatically. The answer is no, but through no fault of the tie line load control equipment. It is characteristic with present day turbine governors, both steam and hydro electro to "rob" load from one another if several units are assigned jointly to frequency control. This condition tends to aggravate the governor performance to such an extent that frequency control becomes unsatisfactory. When the chart showing the performance of automatic load control equipment was made the frequency was being controlled by one of the northern steam plants, probably Windsor.

What probably is confusing Treat is how generating plant loads are adjusted south of this tie to meet rapid load changes. For instance, the early morning load increase south of this tie is in excess of 250,000 kw during a one hour period. Of this increase, the tie line automatically controlled, contributes probably less than 5 per cent, and

that only momentarily. The answer is that the tie line load controlling plant acts as a vernier load adjuster. Certain other plants in the area have their loads changed manually according to a schedule previously anticipated by the load dispatchers. Obviously, if the load dispatcher's forecast is correct within 10 per cent, the tie line load regulating plant has little difficulty in maintaining a fairly constant load on the tie.

E. E. George refers to the author's and his associates' contribution to the governor problem. This hardly can be called a contribution; however, it promises a solution of many problems relative to uniform speed control. This development might be termed an electrical governor. Fly balls, restoring rods, and synchronizing motors have been discarded, thus eliminating the time element required for the response of heavy masses, linkages, restoring mechanisms, and motor inertia. The governor prevents creeping of the turbine gates or valves, is practically instantaneous in response, and is highly sensitive to the most minute speed change.

This governor is being developed primarily for 2 purposes: first, as a means of simplifying the co-ordination of tie line load control and frequency control; second, to permit the assignment of frequency control to as many generating units or plants as desired irrespective of their location. It is proposed to accomplish this by eliminating creeping of gates with consequent unintentional load change on the unit and through a rate of response to intentional load changes on the unit many times faster than can be accomplished with present day governors. Tests indicate there is no tendency of generators equipped with these governors to "rob" load from each other. In fact, indications are that the control can be so adjusted that units assigned to frequency regulation can be made to cover their most efficient loading range, irrespective of shapes of efficiency curves, all in unison, regardless of the number.

That Marquis, who has spent a great deal of time in studying the tie line load and frequency control problems, is optimistic over the ultimate accomplishment of satisfactory co-ordination of tie line load control and frequency control is encouraging.

Torque in a Bipolar Induction Meter

Discussion of a paper by Ralph M. Morton published in the April 1936 issue, pages 354–8.

A. T. Sinks and **H. E. Trekell** (General Electric Co., West Lynn, Mass.): R. M. Morton's analysis is a good interpretation of the eddy current action of producing torque in a meter disk and should be of value for several applications, including other forms of induction motors. The accuracy is best if the poles are close together and if they are placed some distance away from the disk boundary. For commercial meter designs these conditions are fulfilled even to a greater extent than Morton has indicated. Often the poles carrying fluxes out of phase are placed near each other and in some cases are overlapping. For such conditions this theory applied with due regard to its practical limitations, such as flux angularity and distribution, should give reliable results. For the condition of 3 poles, 2 of which are of opposite polarity but carry the same flux, superposition of the effects of each acting separately may be made to give the effect of both acting together shown in figure 1 of this discussion.

Morton has assumed the position of the point pole to be nearer one edge of the actual pole boundary so that an eddy current path near the edge of the pole falls upon the equivalent round pole. To the writers it seems more reasonable to locate the point at the center of the actual pole for all eddy currents outside the boundary of the actual pole. The reason for this is that the field shown in figure 1 of the paper in reality is the result of the superposition of 2 fields, each produced by lines of magnetic flux concentrated at a point of an infinite plane. Each of these individual fields will be represented, of course, by concentric circles and the current density will vary inversely with the distance from the center point. A circular pole of finite dimensions in an infinite plane, however, will produce exactly the same field at all points outside its own boundary, provided the flux density is uniform under the pole. Since the flux density under the pole also is assumed to be uniform, actually the field resulting from 2 poles acting together will be the field obtained by the superposition of the 2 separate circular fields which, as shown by the foregoing discussion, are the same as the fields produced by a point pole at the center of each actual pole. Hence, the mathematical point pole should be located at the center of the equivalent circular pole in computing the current outside the pole boundary. This change in the analysis moves the point pole toward the center of the disk. From the computed data in table I of the paper it is quite evident that the effect of moving the point pole toward the edge of the disk is to decrease the computed torque; consequently, the modification outlined in the foregoing discussion should improve the accuracy of the calculations, particularly when the pole is near the edge of the disk.

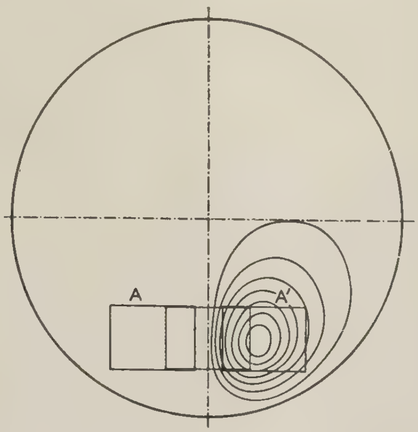


Fig. 1. Diagram illustrating eddy currents in half of disk caused by 2 poles *A* and *A′* of opposite polarity

The method just described also can be extended to compute the currents under the pole, if it is recognized that the current density under a single pole with uniform flux density in an infinite plane is proportional to the distance from the center. Superposition of this current on the current produced by the corresponding image pole would produce the actual current under the pole.

In reality the poles are rectangular instead of round and this difference probably makes considerable difference if the poles are very close together; also in actual practice the flux density under the pole is likely to be very irregular.

Automatic Control for Mercury Arc Rectifiers

Discussion of a paper by H. Bany and M. E. Reagan published in the January 1936 issue, pages 100–09, and presented for oral discussion at the automatic stations session of the winter convention, New York, N. Y., January 29, 1936.

R. B. Arthur (Brooklyn Manhattan Transit Corp., Brooklyn, N. Y.): A real feature of the mercury arc rectifier is the simplicity of its control, thus lending itself to unattended installations. The protection features of unattended installations are of particular interest. The question as to whether particular troubles should result in shutdown or lockout depends somewhat on the particular installation. As pointed out in the paper, undesirable conditions that may correct themselves need only result in the temporary shutdown, whereas those requiring inspection of the equipment to determine that it is in safe operating condition before being placed in service again should result in a lockout. However, unless the abnormal conditions resulting in shutdown are able to correct themselves in a short period of time, or unless there will in some way be an indication of what caused the shutdown, it is believed that it is better to have such a condition result in lockout so that the operator will have knowledge of the cause of the trouble and give proper attention to the device not functioning properly.

Although simplicity is desirable it is not thought that this should be carried to the point where the protection of the equipment should depend on one device only.

It will be noted that in the scheme outlined in the paper that there is a reasonable use of "backing up" features.

D. C. Hoffman (General Electric Co., Philadelphia, Pa.): Automatic control for machines in unattended stations usually is designed for maximum continuity of service, but it must also protect the machine against damage due to continued operation under abnormal conditions. General practice is to shut down a machine temporarily if the abnormal condition is of a temporary or self-corrective nature. If the trouble is of a serious nature, or is not self-corrective, the machine is shut down and locked out by means of hand reset devices.

Rotating machines inherently are subject to a greater variety of troubles that are not self-corrective, such as overheated bearings, grounded or short circuited windings, serious flashover, loss of field excitation, and

overspeed. Hence, the control for rotating machines includes a greater number of hand reset devices, or protective relays that operate a hand reset lockout relay. The control for rectifiers includes comparatively few lockout features because most rectifier troubles are of a self-corrective or temporary nature. The rectifier is therefore shut down temporarily and put back into service as soon as the trouble has corrected itself, thereby insuring maximum continuity of service.

Generally, a rectifier is locked out only after a predetermined number of successive arc-backs have occurred, indicating an abnormal condition that requires human attention. In some cases, lockout also occurs in case of severe overcurrent such as would be caused by a fault in the primary windings of the power transformer. Hand reset devices can be provided, of course, to protect against any abnormal condition if such features are desired in any particular installation.

Self-Excitation of a Frequency Converter

Discussion and author's closure of a paper by Oscar Hess published in the December 1935 issue, pages 1359–66, and presented for oral discussion at the electrical machinery session of the winter convention, New York, N. Y., January 29, 1936.

R. E. Hellmund (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): This paper is necessarily somewhat involved on account of the many factors to be considered. In accordance with actual practice the theory given relates to a 3 phase arrangement, which is further complicated by the necessity of using several combined field windings of different phase relations for each pole in order to obtain the proper excitation. This in turn makes it somewhat difficult to understand the principle of self-excitation in a-c commutator machines. It may, therefore, be helpful to refer to what I believe was the first and simplest self-excited a-c commutator generator. This generator was operated as early as 1904 in work carried on by William Stanley in connection with the development of self-compounding alternators.

It was discovered at that time that an induction machine used as a generator and excited by low frequency had certain compounding characteristics, and the problem was to find a suitable low frequency machine to serve as an exciter. It was realized that because of the low frequency a synchronous machine would be too large for this purpose and a commutator machine was therefore used.

The 2 phase machine A in figure 1 of this discussion shows the earliest arrangement used by Stanley. Since the possibility of self-excitation was not originally appreciated, the fields b and c were excited from a small 2 phase synchronous machine D, a condition obtained with the various switches (1, 2, 3, and 4) in the position indicated by the full lines. It is at once evident that with this separate excitation the armature e will generate 2 phase current between the pairs of brushes fg and hk. If the ohmic drop is neglected for the present, the fluxes in the fields b and c are 90 degrees behind the voltages E_1' and E_2'. This in turn means that the voltage E_1 generated between brushes f and g is 90 degrees out of phase with voltage E_2' and therefore in phase with the voltage E_1', and, similarly, the voltage E_2 between brushes h and k is in phase with E_2'. If the speed is now adjusted so that the voltages E_1 and E_2 are equal to E_1' and E_2' in amplitude, it is evident that the switches can be moved to the position indicated by the dotted lines. The voltages then impressed upon the fields b and c would remain unaltered in phase and amplitude, and consequently the machine will continue to operate at the same frequency and same voltage as before but will be self-excited. (It is further assumed that the armature currents are fully compensated for by a stator winding.)

In reality, the principle of self-excitation was not arrived at in this manner, but Faccioli found by experimentation that the machine could be made to pick up self-excitation by temporarily shifting the brushes by 90 degrees and then returning them to the position shown in the figure. When this was first done, it so happened that the self-excited machine gave the desired voltage but gave a frequency about double that which was wanted for the excitation of the induction machine, and the problem then arose as to how the machine design or other conditions could be changed to give the desired frequency. In those early days this seemed to be quite a mystery but soon a very simple explanation was found. The voltage E_1 is proportional to the speed and the flux but independent of the frequency. In order to have equilibrium the self-inductive voltage in the field winding c must be equal and opposite to E_1.

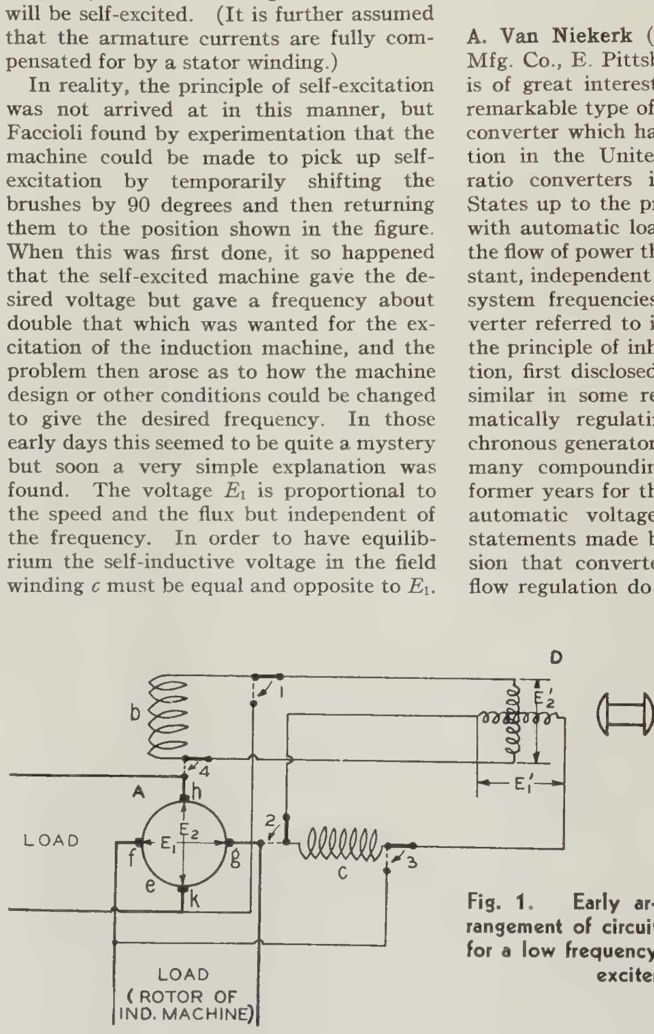


Fig. 1. Early arrangement of circuit for a low frequency exciter

This field voltage is proportional to the field, the frequency, and the number of field turns. It thus becomes evident that by doubling the field turns the desired voltage can be induced in c with the same field and with half the frequency, thus giving the desired results. The case illustrated in the figure is one of shunt self-excitation, but it can be readily seen that series or compound windings also can bring about self-excitation under suitable conditions.

These considerations not only give a simple explanation of a-c self-excitation, but also plainly indicate that self-excitation of a-c commutator machines at frequencies determined by certain machine and circuit constants is as legitimate as the self-excitation of d-c machines, although slightly more complicated. Therefore, it always seemed to me rather risky to apply commutator machines, with the possibility of self-excitation, as part of such an important and costly arrangement as the frequency changer described in the paper. Although, as mentioned in the paper, self-excitation can be avoided under certain normal operating conditions, it is difficult to foresee the conditions during transients or abnormal operation when self-excitation may occur and affect unfavorably the operation of relaying, regulating, and protective devices just at the time when their proper functioning may be vitally important.

A. Van Niekerk (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): This paper is of great interest because it relates to a remarkable type of variable-ratio frequency converter which has not yet found application in the United States. All variable-ratio converters installed in the United States up to the present time are equipped with automatic load regulators for keeping the flow of power through the converter constant, independent of the fluctuations of the system frequencies, but the type of converter referred to in this paper operates on the principle of inherent power flow regulation, first disclosed by W. Seiz, a principle similar in some respects to that of automatically regulating the voltage of synchronous generators by means of one of the many compounding schemes proposed in former years for the purpose of eliminating automatic voltage regulators. Since the statements made by Hess give the impression that converters with inherent power flow regulation do not need any automatic load regulating devices at all (except in those cases where it is desired to vary the power flow depending on the relative changes in system frequencies), I should like to ask in the first place if this impression is in agreement with the actual situation. In this connection I wish to mention that in 1930 I had an opportunity to see 2 such converter sets in regular operation; the first one was the 4,000 kw "Arbed-Terres Rouges" set in Esch (Luxembourg), built by Brown-Boveri (Seiz) and equipped with a Scherbius machine; the second one was the 20,000 kva "Pfrombach" set near Munich, built by Siemens-Schuckert (Osanna) and equipped with 2 single-phase commutator machines in the 2 phase rotor circuit of the main induction machine. On both occasions I heard that, on account of secondary effects, the power flow could not be held constant within sufficiently close limits by inherent regulation alone, and that for this reason supplementary load regulators had to be provided, not only for the 2 sets just mentioned, but also for others

which were under construction at that time. Curves published by Seiz showed, for instance, that in the case of the "Arbed-Terres Rouges" set the change in power flow over the entire frequency range amounted to 20 per cent of the rated output. Could Hess tell whether later developments or refinements of the exciter equipment of the Scherbius machines have made it feasible to omit the supplementary automatic load regulators?

At that time I also came to the conclusion that in comparison with a variable-ratio frequency converter set equipped with automatic load regulators, the probability of the occurrence of self-excitation of a set with inherent power control would be much greater. Since my conclusion was not the result of a detailed comparative analysis of the self-excitation possibilities in the 2 cases, I would appreciate it if Hess could state if in his opinion my conclusion was correct.

Since the paper by Hess is devoted almost entirely to the discussion of a case where self-excitation of a-c apparatus is decidedly harmful and should be avoided at any cost, it might be well to emphasize that in certain instances it may be used to advantage as an operating principle. For instance, it is known that an induction machine can be made self-exciting by concatenating it with a self-excited a-c exciter (3 phase commutator machine), so that it can be used to supply power to a dead load, generating a-c currents of a quite definite frequency in the complete absence of synchronous machinery. Perhaps the first industrial application of this kind was the installation of a 230-kva independent and self-exciting generating unit consisting of an induction machine concatenated with an a-c exciter, built by Siemens-Schuckert, in 1926. A self-excited commutator generator, developed and built in the United States for the purpose of supplying low-frequency currents to induction motors, was described in reference 2 of Hess's paper. These recent developments are sufficient proof that there are still many possibilities involving successful applications of polyphase commutator machines.

Oscar Hess: In answering first A. Van Niekerk's question regarding the degree of constancy of the power transfer, I should like to refer to the third paragraph of the paper (page 1363). The question whether a given converter needs automatic load regulators or not depends first upon the desired degree of constancy and second upon the problem whether a given requirement can most economically be met in 1 of 3 different ways, namely, by reducing the magnitude of the different disturbing influences, by compensating them by means of auxiliary circuits, or by the use of load regulators. If the transferred power is not allowed to vary more than a few per cent or if special regulating requirements have to be met, automatic load regulators can hardly be dispensed with. It is, however, believed that the 20 per cent power variation, referred to by Van Niekerk, could be reduced without automatic load regulators by taking advantage of the better understanding of the proper design gained from theoretical studies and practical experience.

Concerning the probability of self-excitation of the Seiz converter I may say that the converter operates close enough to self-excitation that a detailed study of this phenomenon is necessary. Although it is true that the Seiz converter operates closer to self-excitation than those equipped with automatic load regulators, it should be born in mind that self-excitation will not occur whether 50 per cent or only 10 per cent of the ampere turns necessary for self-excitation are lacking. As a number of means are available to bring the ratio of the available to the necessary ampere turns to a figure sufficiently below unity, it is in most cases technically possible to eliminate the danger of self-excitation. Whether such a solution will also be economical is a question which can be answered only in specific cases. I agree, however, with R. E. Hellmund that the fundamental requirement for the application of the Seiz converter is the certainty that no risks regarding self-excitation are incurred.

"Angle Switching" of Synchronous Motors

Discussion and authors' closure of a paper by C. C. Shutt and J. W. Dawson published in the November 1935 issue, pages 1191–5, and presented for oral discussion at the synchronous machines session of the winter convention, New York, N. Y. January 29, 1936.

M. R. Lory (nonmember, Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): It is evident from the commercial installations described by the authors that angle switching of synchronous motors has progressed beyond the experimental stage. Its use for the present will be confined to special applications where the advantages offset the increased cost of the control. In many cases special motor designs will be used to advantage with angle switching.

First consider drives such as centrifugal pumps and blowers which require high pull-in torque but only moderate starting torque. Motors for these drives can often be made both smaller and with the lower inrush when designed for use with angle switching. One effect of making a given motor smaller is to increase the reactance. This increased reactance reduces the starting current but also reduces the torques. Angle switching enables the motor to pull in the load in spite of its decreased pull-in torque and the low starting torque of the motor is adequate for these applications. Of course, it will be impossible to reduce the motor size where the frame size is determined by considerations other than torque, but especially in low speed motors the size is often fixed by the torque requirements.

Motors for applications requiring high starting torque as well as high pull-in torque can sometimes be reduced in size or designed for lower inrush, but it is usually impossible to obtain both of these advantages. This becomes evident if we consider a design of low inrush. In order to maintain high starting torque with the reduced inrush, it is necessary to improve the locked power factor. This requires a high resistance damper winding and low machine reactance. To obtain low reactance requires a large machine and thus the frame size cannot be reduced. The high resistance damper winding reduces the pull-in torque but the angle switching functions to take care of this limitation.

Angle switching has many possibilities when used with motors properly designed for use with it. It must be borne in mind, however, that the success of such installations is largely dependent on the control used. The angle switching device must provide accurate timing of the field application and should be simple, reliable, relatively inexpensive, and easily adapted to existing forms of control. It seems to me that the device described by the authors fits these requirements very well.

D. R. Shoults, S. B. Crary and **A. H. Lauder** (all of General Electric Co., Schenectady, N. Y.): This paper presents further test information as to the advantages to be gained from applying field at the most favorable point of the slip cycle. Unfortunately, there appear to be discrepancies between the illustrations and text material in the designation of the angular displacements which, if the authors would correct, would greatly increase the value of their paper.

If zero angular displacement is defined as that corresponding to no load, which is the usual definition, then, we believe, figure 5 should be marked 180 degrees where it is now marked 0 degrees and 0 where it is now marked 180 degrees. This would bring the point of most favorable switching at about 20 degrees from the zero position in the motor region and the point of most unfavorable switching at 140 degrees from the zero position in the motor region. This would bring the results of Shutt and Dawson into correspondence with the theoretical approach to the problem and with the test results which we have obtained on several different motors.

Figures 8 and 9 apparently have typographical errors in the captions, for the words motoring and generating are interchanged from their use in the text.

It would also be of interest to know whether the angles referred to in the text are the actual angles of the rotor at the instant that field is applied or if a correction for relay and field contactor time must be made.

R. C. Scott (Mutual Boiler Insurance Co., Boston, Mass.): This paper tends to establish the practical usefulness of the "angle switching" method of synchronizing, and confirms the predictions contained in earlier papers by Edgerton and his associates. The more important advantages to be derived from angle switching, such as increase in starting torque, reduction of starting currents and resulting voltage disturbances, are well illustrated.

The actuating mechanism utilizing a small induction pilot generator and vacuum tube is of interest. This arrangement would appear to limit its use to a relatively small number of special applications because of the necessity of mounting the induction generator on the shaft of the main motor and also because of the cost.

In regard to means for effecting angle switching, probably the first description of a practical arrangement was presented in the writer's thesis on the subject, submitted to the Massachusetts Institute of Technology in 1932.

This early arrangement, which comprised a combination of polarized and time-delay relays, proved to be entirely satisfactory in principle. Subsequently, the equivalent arrangement shown in figure 1 of this discussion was devised, in which the polarized relay is replaced by 2 half-wave rectifiers.

As shown on the diagram, starting is "across the line" and the time delay relay *RL*-1, which initiates the operation of angle switching relays, is adjusted to close its contacts when the rotor has accelerated to its maximum induction-motor speed. The induced current in the field when the motor is operating at its maximum induction-motor speed is represented by figure 2 of this discussion. Let the most favorable angular position of the field poles relative to the impressed voltage for pulling into step be represented on the wave of induced field current by the point *c*.

Then the selector relay *RL*-2 will close its contacts at the point *a* in figure 3 and will be held in the closed position by its holding coil. When the polarity of the field current is reversed, the selector relay *RL*-3 will in turn close its contacts at the point *b* and will be held in the closed position by its holding coil. The time delay relay *RL*-4 will then be immediately energized and by suitably adjusting its timing, the field switch will be closed at the point *c*. After the field switch is closed all relays will drop out.

If the most favorable angle is represented on the wave of induced field current by the point *d*, or if the "time" between points *b* and *c* is too small, time delay relay *RL*-4 may be adjusted to close the field a cycle later.

When the angle at which the field is switched is most favorable, the armature current will immediately be reduced to its steady state synchronous motor value, without first exceeding its maximum induction motor value. This fact affords an easy method of determining by trial the correct setting of time delay relay *RL*-4.

Whatever detail of switching arrangement is employed, it seems likely that the broad principle of angle switching with its attending benefits, not only in starting characteristics but also in capital and operating costs, has now been firmly established. In fact, it is probable that the time has arrived where it may be regarded as a mistake to purchase synchronous motors, even of comparatively small capacities, that have not been designed for use with this valuable adjunct.

E. E. George (Tennessee Electric Power Co., Chattanooga): It is interesting to note that mechanical methods of integration have resulted in considerable interest in analyzing synchronous motor starting phenomena. In *Electrical World* for April 10, 1920, and for January 22, 1921, the writer worked out a solution for the pull-in torque of synchronous motors and showed that the angle at which field excitation was impressed had a very important relation to the starting current and to the maximum load which could be started. While accurate numerical results may not have been obtained, and while the torque expressions were derived long before the invention of the direct axis and transverse axis notation, the discussion of the physical basis of starting and the recommendations are apparently valid.

C. C. Shutt and **J. W. Dawson:** It is quite interesting to note that the discussions bring out a trend toward the practical application of the theoretical work which has been done on the "pulling-into-step process" of synchronous motors.

The means of accomplishing angle switching, which have been pointed out in the discussion by R. C. Scott, appear to depend upon the time delay setting of a relay (*RL*-4) which is energized after the operation of 2 polarized relays or their equivalent. This should give a rather accurate angle setting provided the balancing speed or slip of the motor is on its starting winding. But if the average slip varies from one start to the next, from a variation in load or terminal voltage, it would appear to cause a considerable variation in the angle at which the field is applied. This is because with different values of slip the rotor will move through a different number of electrical degrees during a fixed time of operation of the relay.

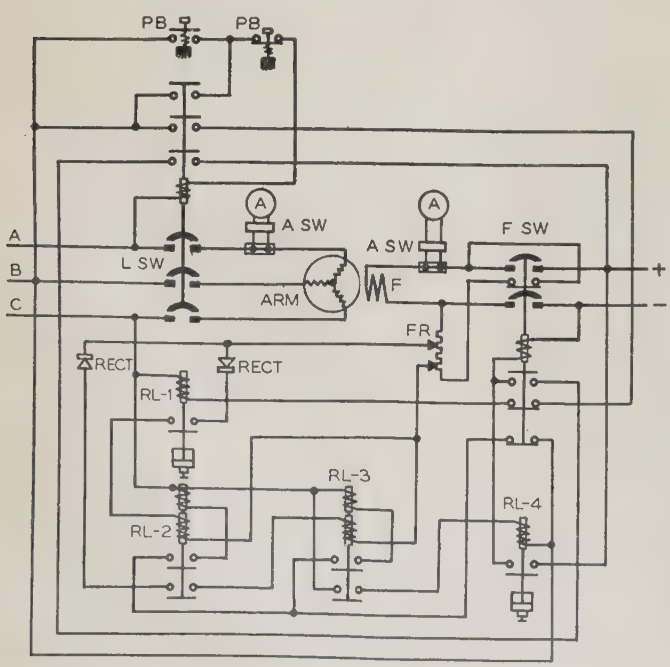


Fig. 1. Synchronous motor starting system

A—Ammeter
A Sw—Ammeter switch
Arm—Armature
F—Field
FR—Field resistance
F Sw—Field switch
L Sw—Line switch
PB—Push button
Rect—Rectifier
RL-1—Time delay relay
RL-2—Instantaneous relay
RL-3—Instantaneous relay
RL-4—Time delay relay

In regard to the discussion by Shoults, Crary, and Lauder, it is difficult to compare our test results with theirs, since they have presented no test results. The designations of the angles are quite conventional. As pointed out in paragraph 3 of the paper, 0 degrees refers to true no-load position. The 180 degrees ahead of this position is called

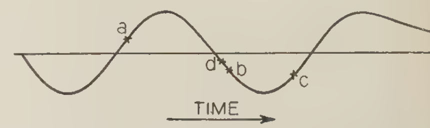


Fig. 2. Wave of induced field current

the generator region, and the 180 degrees behind it is the motor region. The designations of figures 1 and 5 and the accompanying text are correct. It should be noted in connection with figure 1*b* that the text clearly states that the arrows refer to the impressed voltage. A casual examination of the figure might lead to the conclusion that the arrows refer to direction of the induced voltage. In that case, the impression is that the figure is 180 degrees off.

Through a typographical error the words "generating" and "motoring" are interchanged in the captions of figures 8 and 9.

Pull-In Characteristics of Synchronous Motors

Discussion and authors' closure of a paper by D. R. Shoults, S. B. Crary, and A. H. Lauder published in the December 1935 issue, pages 1385–95, presented for oral discussion at the synchronous machines session of the winter convention, New York, N. Y., January 29, 1936.

H. E. Edgerton (Massachusetts Institute of Technology, Cambridge): The authors are to be congratulated upon their comprehensive study of the pull-in problem. It is unfortunate that such a comprehensive study must need to be made for every motor to get the exact conditions, and that it is impossible to obtain generalized solutions that can be applied to all machines. This, however, in the future will be no disadvantage because differential analyzers are becoming a commonly used calculating device. I do not doubt that sometime all the larger companies will have differential analyzers available for doing their engineering calculations, just as they have adding machines to figure out how much money they make.

Three years ago the differential analyzer at Massachusetts Institute of Technology was the only one available. There are now 3 other differential analyzers, 2 in the United States and one at the University of Man-

chester, England, built by Dr. D. R. Hartree. Another is under construction at the observatory of the Astrophysical Institute at Oslo, Norway, by Dr. S. Roseland, and another is under consideration in America at one of the larger universities. Dr. Vannevar Bush and Dr. S. H. Caldwell at M.I.T., with a staff of 6 men are now actively engaged in the development of an entirely new machine designed to handle differential equations with the same relative ease as one enjoys in using a keyboard machine for ordinary computations. Its principal features are: improved precision, greater range, and much higher speed, plus the complete elimination of manual control.

Irven Travis (University of Pennsylvania, Philadelphia) and **C. N. Weygandt** (nonmember; University of Pennsylvania, Philadelphia): The authors are to be congratulated on their very excellent paper. The close check between theoretical and experimental results leaves no doubt as to the fundamental correctness of the equations and the method of their solution.

Several interesting questions of differential analyzer technique arose during the course of the work which led up to this paper. The first was in setting up equations 1 and 2 on the machine. The normal method of handling such equations would be to solve them for $p\,\psi_d$ and $p\,\psi_q$.

$$p\psi_d = e \sin \delta + \psi_q + ri_d + \psi_q \frac{d}{dt}$$

$$p\psi_q = e \cos \delta - \psi_d + ri_q - \psi_d \frac{d}{dt}$$

Hence ψ_d and ψ_q could each be evaluated by the use of a single integrator. However, if this were done a serious cumulative error would be introduced. In equations 1 and 2$e \sin \delta$ is approximately equal to ψ_q and e

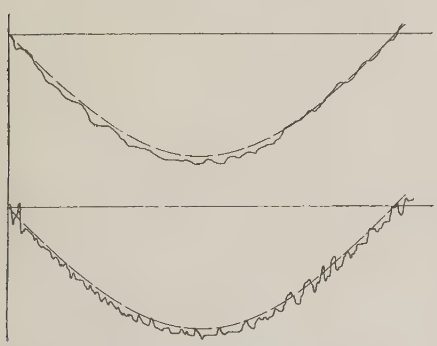


Fig. 1. Curves showing accuracy of approximating a cosine function with mechanical input

Top curve for slow turning; bottom curve for fast turning

$\cos \delta$ is approximately equal to ψ_d. The other terms are in the nature of correction terms; in fact, in previous work these terms have frequently been neglected. For this reason $p\psi_d$ is essentially a small difference of the relatively large quantities $e \sin \delta$ and ψ_q, and similarly $p\,\psi_q$ is essentially a small difference of the relatively large quantities $e \cos \delta$ and ψ_d. Suppose that a slight error were to be introduced in $e \sin \delta$ for any reason, for example by failure of the operator to follow exactly the sine curve. Such an error when integrated would immediately affect ψ_d, which in turn would be introduced into equation 2. The resultant error in ψ_q as obtained from equation 2 is fed back into equation 1, possibly in such a direction as to increase the original error in ψ_d. It can be readily seen that this process can repeat itself so that a tremendous error would be built up. In order to avoid this difficulty the scheme described by the authors was used. Some tests were made of the accuracy of this method of using an integrator to differentiate. A set-up was made whereby the result of differentiating a cosine function was compared with a true sine wave. Figures 1 and 2 of this discussion are the results of some of these tests. For figure 1 the function being differentiated was generated mechanically by solving the harmonic differential equation, and for figure 2 it was obtained from an input table. Since it is impossible for an operator to follow the plotted curve exactly, the function being differentiated in figure 2 is a much poorer approximation to a cosine than the function in figure 1.

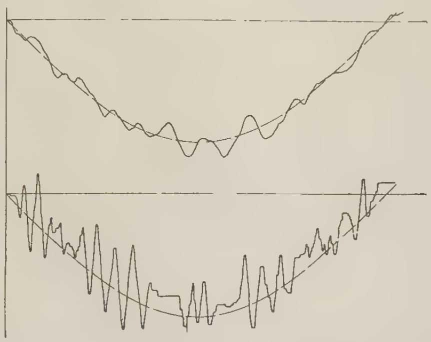


Fig. 2. Curves showing accuracy of approximating a cosine function with manual input

Top curve for slow turning; bottom curve for fast turning

The operator of a differentiator may adopt either of 2 techniques. He may, regardless of the danger of overshooting, attempt to bring the indicating element of the adder back to its zero position whenever it deviates from that position. This results in a derivative which oscillates with considerable amplitude about the true curve as shown in the curves marked "fast turning." He may on the contrary simply attempt to hold the indicating element of the adder as still as possible regardless of the danger of introducing an error in the average value. This results in a much smoother curve as shown in the curves marked "slow turning." Since $p\,\psi_d$ and $p\,\psi_q$ were correction terms changing the final result only about 5 per cent, and as the error in evaluating these quantities was on the average less than 10 per cent the net error in the results introduced by this method of differentiation appears to be less than 0.5 per cent.

R. C. Buehl (Enrolled Student, Massachusetts Institute of Technology, Cambridge): Several years ago (1932–33) at the Massachusetts Institute of Technology, I investigated with N. I. Mostafa the pull-in characteristics of synchronous motors when the field switching angle was controlled. The switching method (figure 3 of this discussion) consisted of a disk with a narrow slit connected to the shaft of the motor and illuminated with a stroboscope which made it appear to turn at slip speed. A photoelectric tube placed behind the disk was illuminated by the stroboscope through the slit causing the excitation voltage to be applied when the slit was in front of the photoelectric tube at the time of a stroboscopic flash. The only source of appreciable delay was in the field switch, which was minimized and corrected for. The phase of the stroboscopic light with respect to the applied voltage was controlled by a phase shifter.

The main purpose of the investigation was to determine whether the integraph solutions made at M.I.T. (references 9 and 10 of the paper) were useful from a practical standpoint. The tests were made on a 44-kw wound-rotor motor for which the constants of the equation could be conveniently varied by changing the field resistance and adding inductance to the primary. The results on this machine checked the integraph solutions to within 5 per cent. A 160-kw salient-pole synchronous motor was also investigated and the gain due to controlled switching agreed well with the integraph solutions.

These results indicate that when the field resistance is not changed on applying field excitation, and the field transients are shorter than the mechanical oscillations, the results of the generalized integraph solutions made at M.I.T. are valid. In practice these conditions are not entirely satisfied, and the paper presents an excellent treatment of the other factors that contribute to the solution. Unfortunately the problem cannot be solved in a generalized form when all the factors are rigorously included.

C. C. Shutt (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): This paper is a very definite contribution to the technical literature on the subject. The pulling into step process of a synchronous motor definitely represents a transient condition and should be investigated by such a fundamental study of the flux linkages.

Previous authors have set up the fundamental differential equation with the synchronizing power of the machine represented as the steady state maximum torque times a function of the sine of the angular displacement, and in one case, also included an exponential function of time. Our tests have indicated conclusively that the maximum torques developed are considerably in excess of the steady state pull out torque. For example, an analysis of the film given as figure 6 of the paper " 'Angle Switching' of Synchronous Motors" (C. C. Shutt and J. W. Dawson, Elec. Engg., v. 54, Nov. 1935, p. 1191–5) shows that the maximum electrical torque developed, exclusive of induction motor torque, is 1,050 pound feet while the steady state pull-out is 675 pound feet. Other tests show even greater variations.

One of the conclusions reached by the authors in their study is that the most favorable angle for maximum pull-in torque is 30 degrees in the motoring region. However, this is not necessarily a generally correct angle.

This 30 degrees, for the machine they studied, represents the angle between the impressed 3 phase voltage, referred to the rotor, and the field current. As such it is the sum of the impedance angle of the field winding circuit and the angle by which the induced voltage is displaced from the terminal voltage by the stator leakage reactance drop. If the leakage reactances of these 2 windings were very small, the angle would be practically zero. In such a motor the time constant would be zero and the switching angle for maximum torque would be at zero displacement. Calculations show values of this angle as low as from 10 to 15 degrees in some cases.

One motor investigated by the writer was rated 900 horsepower at 720 rpm, and had a total angle between the impressed voltage and the field current of 25 degrees and a short circuit time constant of 0.53 second. This motor was connected to a load which had a moment of inertia equal to about 50 per cent of the motor rotor. Since this motor has a long time constant for its rating and a low total moment of inertia, the switching angle for maximum torque was found to be about 20 degrees in the motoring region.

A motor which had quite different characteristics was rated 290 horsepower at 1,200 rpm. It was connected to a generator with a value of rotor moment of inertia practically equal to that of the motor. The short circuit time constant of the field winding was only 0.175 second and over $^1/_4$ second was required for the motor to become synchronized. With this machine the region for best synchronizing was around 30 degrees in the generator region. Also, the worst angle was at the 60 degree motoring position. With short time constants and high moment of inertia values it appears best to apply the excitation while the rotor is still in the generator region.

The results of a large number of tests on machines with different time constants and connected loads with different moments of inertia show that, from the standpoint of torque alone, the motor will always pull in against a relatively high value of load torque when the field is applied in the region of generator action. There is always a severe dip in the curve of torque versus angle in the motor region. This makes angle switching in the initial portion of the motor region very critical. Since with increasing time the motor passes from zero angle further into the motor region, any slight delay in the operation of the contactors may result in switching from a very unfavorable angle.

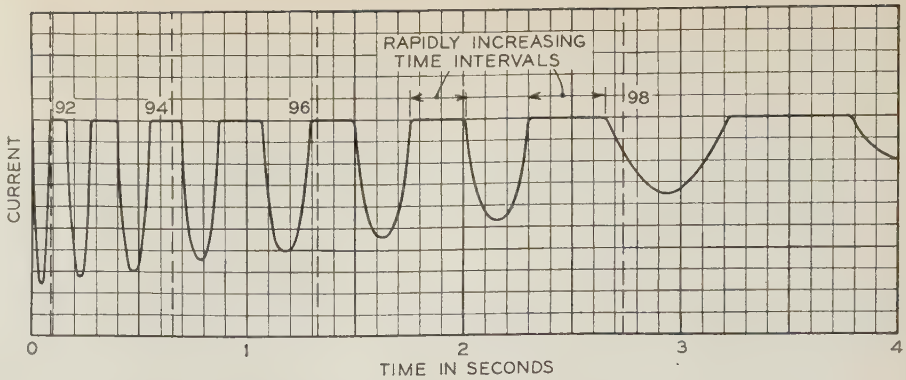


Fig. 4. Diagram showing half waves of induced current of rapidly decreasing frequency which are applied to relay coil. Numerals indicate per cent speed

M. N. Halberg (General Electric Co., Schenectady, N. Y.): It has long been recognized that the pull-in torque of a synchronous motor may vary appreciably with the point in the slip cycle at which excitation is applied. Furthermore, there have been devised a number of different control arrangements for applying excitation at a favorable angle and these have been used in a few special cases. Yet, until quite recently, there has been no general application of control equipment of this type.

The first of some possible reasons for this is that previous investigations indicated that the gain in pull-in torque, if any, was rather small for machines having a long time constant. As shown by the solutions of the authors and also by the various test results presented, this is not the case; that is, the gain in pull-in torque is substantial even for motors with long time constants. Secondly, there have not been available adequate criteria for predetermining the pull-in torque for both favorable and unfavorable switching conditions. Such criteria have been presented. Finally, the usual control equipment for accomplishing this result has been rather costly and complicated. Although the use of auxiliary generators or other equipment mounted on the motor shaft, electronic tube amplifiers, etc., may be tolerated under special conditions, it can hardly be justified for the large majority of applications. Much simpler equipment is necessary if it is to be used generally.

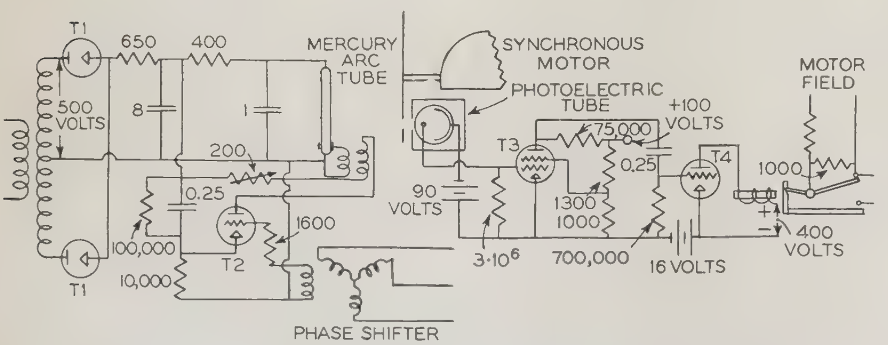


Fig. 3. Diagram of a switching method used in investigating pull-in characteristics of synchronous motors

T1—Type 83 full-wave mercury-vapor rectifier tube

T3—Type 47 pentode amplifier tube

T2, T4—Grid-controlled mercury vapor tube

Resistances are given in ohms; capacitances in microfarads

In this connection, it might be of interest to note that a few years ago H. T. Seeley devised a rather simple field application relay which operates not only at a predetermined slip but also at a definite point in the slip cycle. This relay, which is of the flux-decay time-delay type, has its coil connected across a section of the field discharge resistor, in series with a copper oxide rectifier. During the starting period induced field current of slip frequency flows through the discharge resistor so that half waves of slip frequency current flow through the relay coil (figure 4 of this discussion). Hence, the relay picks up at start and opens its normally closed contacts. A copper jacket is provided on the relay core which delays the decay of flux, giving the relay a short time-delay dropout. At low speeds this prevents the relay from dropping out between the half waves of coil current. However, when the motor reaches a predetermined slip near synchronism, the time interval between half waves of current is sufficient to allow the relay to drop out. By a simple adjustment of the relay, its time setting can be varied so that it will operate at any predetermined slip in the synchronizing range. Since the relay operation is a function of slip speed it gives an extremely accurate indication of motor speed. In addition, the relay drops out at the end of a half cycle of induced field current of predetermined direction. Thus when associated with a suitably designed controller it applies excitation at the proper slip and under the favorable condition of high flux linkages of correct polarity in the field winding. Over 2,000 of these field application relays are already in service.

D. R. Shoults, S. B. Crary, and A. H. Lauder: After studying this problem from a purely theoretical standpoint we were able to draw a number of general conclusions regarding the pull-in characteristics of synchronous motors. These conclusions, as enumerated in our paper, were based upon solutions obtained by means of the differential analyzer.

Since this paper was published we have made a number of tests to determine the validity of these conclusions and are pleased to report that they have been confirmed.

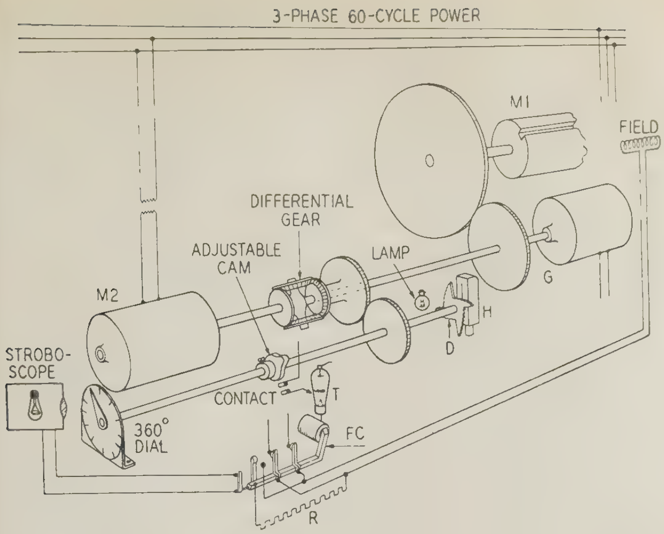


Fig. 5. Arrangement for studying pull-in of a synchronous motor

M1—350 - horsepower 400-rpm synchronous motor

M2—Pilot synchronous motor

D—Displacement angle disc, with 10 degree notches

FC—Field contactor

G—Tachometer generator

H—Photoelectric tube housing

R—Discharge resistor

T—Grid-controlled mercury vapor tube

We believe a discussion of these test results will help to broaden the existing knowledge of this subject, in addition to demonstrating the fundamental correctness of the conclusions arrived at from the theoretical approach.

These tests were made on a 350-horsepower 400-rpm 2,200-volt synchronous motor direct coupled to a larger synchronous machine which was in turn loaded as a generator on a water box. The inertia constant H of the motor and its coupled machine was 2.17. The motor constituted the only load on a 10,000-kva 2,300-volt frequency changer set.

A differential gear (see figure 5 of this discussion) was interposed between a pilot synchronous motor and the main shaft. The gear system was arranged to rotate a countershaft one revolution for each slip cycle. Excitation could be applied at any time during the slip cycle by adjusting a cam on the countershaft. This cam closed contacts in a tube circuit which energized the field contactor. A dial on the end of the countershaft was illuminated by a single flash of light from a stroboscope at the instant the field contactor closed. The angle of application of excitation could thus be read directly from the dial.

On oscillographic records, an indication of angular displacement was obtained by a notched disk on the countershaft revolving between a light source and a photoelectric relay. Slip was indicated by the difference in potential between a tachometer generator and a battery.

The performance of the mechanical system used in this test set-up proved to be a very instructive means of demonstrating the angular displacement of the rotor (δ) as the machine pulled into step. Motion pictures have been taken of a large cardboard indicator on the end of the countershaft under various transient conditions.

Figure 6 of this discussion shows the per unit load torque that could be synchronized with 3 different values of excitation voltage applied at various points in the slip cycle. The field currents shown are the ultimate steady values corresponding to the applied voltages. Prior to exciting the field, the motor was allowed to attain its maximum average speed with the field circuit closed through a 20 ohm discharge resistor (9.1 times field resistance). Maximum load was synchronized when the field was applied at about 345 degrees. This angle is in the motor region approximately 15 degrees beyond the position the rotor would assume when operating in synchronism with no load, and corresponds closely with the point where the induced field current is zero and the field flux linkages are a maximum. The worst angle to apply excitation from a torque standpoint was at 245 degrees. The maximum and minimum points on these curves correspond closely with those predicated by theory. The amount of load that could be synchronized from either the best or worst angles was found to vary only slightly with excitation. The increase in load that can be synchronized by applying excitation at the best angle rather than the worst is about 45 per cent.

Figure 7 of this discussion shows the effect of varying the field discharge resistor on the amount of load that could be synchronized. Minimum slip was attained as an induction motor with the 10 ohm resistor. This reduction in slip was offset by a lower value of field flux linkages so that the load synchronized from the best angle was about the same for either the 10 or 20 ohm resistors.

Figure 8 shows the effect of armature circuit resistance on the amount of load that may be synchronized from any angle. Additional resistance in the armature circuit increases the armature losses resulting from the applied excitation. It also decreases the induction motor torque and necessitates synchronizing a given load from an increased value of slip. This decreases the load that may be pulled in from any angle.

We believe that these test results are in agreement with those published in the paper "Angle Switching of Synchronous Motors" by C. C. Shutt and J. W. Dawson (ELEC. ENGG., v. 54, Nov. 1935, p. 1191–5). In figure 9 of this discussion, one of Shutt and Dawson's curves for 9 ampere field (figure 5 of their paper) has been increased 55 per cent in scale and shifted 180 degrees in angle so that it could be compared with the test curve for 46 ampere field and a 20 ohm resistor, the regions marked generator and motor action by Shutt and Dawson remaining as marked. The 2 curves were taken on motors of radically different ratings but have the same general shape characteristics of synchronizing performance.

Figure 10 of this discussion shows 4 typical sets of oscillographic data taken to record the pull-in phenomena. The poorest angle for the application of excitation, 240 degrees, was selected in the case of oscillogram A. A per unit load of 0.4 was used, which is about the maximum amount that could be synchronized from this angle. The motor slipped a pole and traveled to 220 degrees or

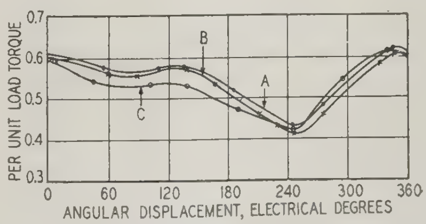


Fig. 6. Pull-in torque versus field application angle characteristics for various values of applied excitation; rated excitation 46 amperes

Curves A, B, and C for field currents of 65, 46, and 25 amperes, respectively. Field discharge resistor 20 ohms; armature circuit resistance 0.029 ohm

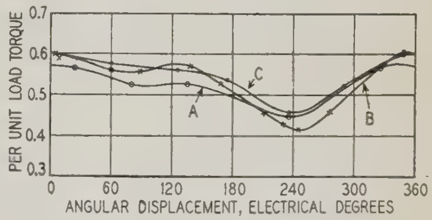


Fig. 7. Pull-in torque versus field application angle characteristics for various values of field discharge resistor

Curves A, B, and C for field discharge resistors of 40, 20, and 10 ohms, respectively. Field resistance 2.2 ohms; field current 46 amperes; armature circuit resistance 0.029 ohm

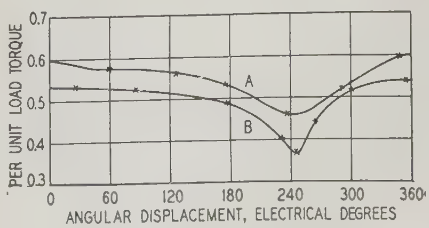


Fig. 8. Effect of armature circuit re istance on pull-in torque

Curves A and B for armature circuit resistances of 0.029 and 0.055 ohm, respectively. Field current 46 amperes; field discharge resistor 10 ohms

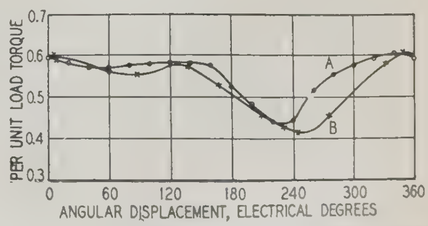


Fig. 9. Comparison of test results with those obtained by Shutt and Dawson

Curve A from Shutt and Dawson; curve B from test with 46 ampere field and 20 ohm field discharge resistor

140 degrees beyond the no load displacement angle before it attained synchronous speed. This required 39 cycles of a 60 cycle voltage wave. The armature current was high throughout this period, even in the region of zero power. In this case the current drawn from the line was at a low average power factor which would be objectionable in some cases from the standpoint of voltage regulation.

Oscillogram B shows 0.4 per unit load being synchronized when excitation was applied at 120 degrees. Synchronous speed was attained in 34 cycles after the rotor had traveled to an angle of 290 degrees or 70 degrees past the no load point. Less reactive power was drawn from the line during this test than when excitation was applied at 240 degrees.

The application of excitation at the best angle or about 345 degrees is shown on oscillogram C of figure 10 for a per unit load of 0.4. The induced field current was approximately zero and the field flux linkages a positive maximum at this point. Synchronous speed was reached in 10 cycles, the rotor having traveled 70 degrees past the no load angle. The maximum current was not appreciably greater than that drawn during the preceding induction motor cycle and occurred at a good power factor.

Oscillogram D shows 50 per cent greater or 0.6 per unit load being synchronized from a favorable angle of 330 degrees. In this case synchronous speed was attained at an angle of 240 degrees or 120 degrees past the zero angle. The elapsed time in reaching synchronism was 13 cycles.

Examples of the use of the favorable angle criterion and the most unfavorable condition criterion are illustrated on figures 11 and 12 of this discussion. In figure 11, equation 30 of the paper for the load torque T_L is plotted with per unit slip as the abscissa. On the same plot the test torque-slip curve before the excitation was applied is also plotted. The intersection between these 2 curves indicates the maximum torque and the maximum slip against and from which the motor can pull in. For the particular case chosen for illustration, the check between calculation and test is remarkably good. The curve for T_L as obtained from the criterion intersects the test torque slip characteristic almost perpendicularly and therefore provides a very definite intersection.

Figure 12 is an illustration of the most unfavorable condition criterion, the upper curve being a plot of the test torque slip characteristic with the field terminals short-circuited. The curve below this one is for the condition of full load field excitation. The difference in ordinates between these 2 curves is due to the braking torque produced by the field excitation of the synchronous motor when running out of step. As shown on the figure the point of test pullin occurs at 0.043 per unit slip while the criterion as given by equation 38 of the paper when $K_2 = 0.55$ indicates that the maximum slip from which the machine can pull in is 0.037. This indicates that the criterion as used is pessimistic for this case as far as slip is concerned but from the slope of the lower torque-slip characteristic would have given an answer with but little error for the maximum torque that can be pulled in. That is, the maximum torque which could be pulled in under these conditions would be predetermined from the calculated torque slip characteristic with full load field excitation. The intersection of this calculated torque-slip curve with the abscissa corresponding to 0.037 per unit slip would be the maximum calculated load which could be pulled into step. Actual test torque-slip characteristics are used in both examples as these are characteristics which designers of synchronous motors have had considerable experience in calculating and which can be predicted with a reasonable degree of accuracy.

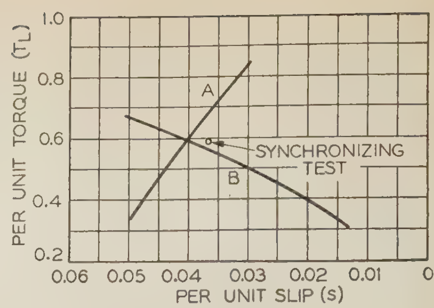


Fig. 11. Illustration of use of favorable angle criterion; full load field excitation

Curve A from equation
Curve B from torque-slip test, 40 ohm discharge resistor

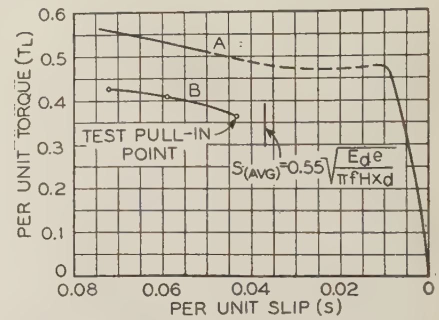


Fig. 12. Illustration of use of most unfavorable condition criterion

Curve A—Test torque-slip characteristic, field terminals shorted
Curve B—Test torque-slip characteristic, 46 ampere field excitation

It is gratifying to us to learn from the discussion that considerable thought is being given to differential analyzer technique and design. We agree that these machines will be used more in the future for solving problems for which the equations already exist but for which the solution is by far a too laborious process by the usual longhand method. The discussion by Irven Travis and C. N. Weygandt brings attention to the fact that there may be more than one way to set up the differential analyzer for the solution of a given problem and that the selection of the best method is a very important detail in the solution.

The discussion by C. C. Shutt, presenting the results on different motors, is of considerable interest to us as it indicates that our test and theoretical results are in general agreement with his tests. He calls attention to the interesting conclusion that the maximum torque developed during pull-in may be in excess of the steady state pull-out even for motors with long time constants. Our test results bear out this conclusion. In oscillogram D, figure 10 of this discussion, the peak power input to the motor only $^1/_{10}$ second after excitation is applied is practically equal to the value at steady state pull-out. The short-circuit time constant of the particular motor is $^4/_{10}$ second, so that the high value of torque obtained must be the result of a transient and not of the applied excitation.

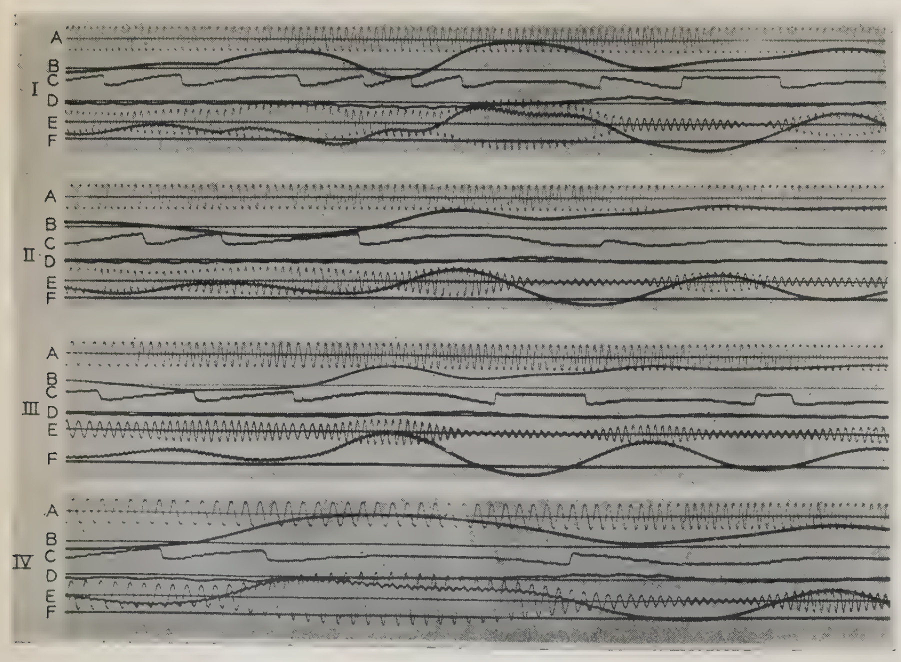


Fig. 10. Oscillograms of pull-in performance with normal excitation applied

Oscillogram I—Excitation applied at 240 degrees, 0.4 per unit load
Oscillogram II—Excitation applied at 120 degrees, 0.4 per unit load
Oscillogram III—Excitation applied at 345 degrees, 0.4 per unit load
Oscillogram IV—Excitation applied at 330 degrees, 0.6 per unit load
A—Line voltage; B—Field current; C—Angular displacement obtained from notched disk and photoelectric unit; D—Slip (voltage from tachometer generator opposed by battery); E—Armature current; F—Stator power input

Pyrochemical Behavior of Cellulose Insulation

Discussion of a paper by F. M. Clark published in the October 1935 issue, pages 1088–94, and presented for oral discussion at the power transmission session of the winter convention, New York, N. Y., January 29, 1936.

C. F. Hill (Westinghouse Elec. and Mfg. Co., East Pittsburgh, Pa.): F. M. Clark's results point out the dangers of overload temperatures on apparatus with class *A* insulation. His results confirm the writer's results obtained some years ago and would seem to justify the 105 degrees centigrade division temperature between class *A* and class *B* types. There are papers somewhat more resistant than the linen selected for this test, and it may be of interest that the writer found paper from pure cotton stock to be better than linen. The author has shown results in vacuum which are comparable to results in air where such volatile material escapes. The writer included tests in which the samples were first dried well, then tested in a nitrogen atmosphere under conditions such that the decomposition products were retained in the space around the paper samples. Such tests emphasize the autoacceleration of the decomposition by the by-products formed. This is explained by the action of several acids forming to react more rapidly with cellulose if water is present. Paper in deep-seated sections of windings might thus be expected to deteriorate more rapidly than more superficial layers, because the moisture and acids from deterioration are held to a greater extent than they are nearer the surface. The writer wonders if this may not be of more importance than the application of voltage in figure 14 of the paper, even though the ionization of acids by voltage might be expected to add some acceleration.

Some data from the author's experiments below 110 degrees centigrade for figure 4 for example would have been quite worthwhile.

The writer should like to ask also whether in the mechanical tests the paper was allowed to come to a standard humidity before testing, or do Clark's results include the decrease in mechanical strength due both to drying and deterioration?

J. B. Whitehead (The Johns Hopkins University, Baltimore, Md.): It has long been known that the properties of paper as insulation are endangered by temperatures above 110 degrees centigrade. This figure has been fixed by experience in manufacture and usage. F. M. Clark's paper, however, is an interesting and valuable study of the nature of the changes caused in paper by temperature elevation, and also of their quantitative relationship to the important electrical properties. Manufacturers and users of paper insulation will have satisfaction in knowing that the safe temperature limits evolved in practice are confirmed by the author's results.

The preheating of paper for insulation is important for the drying process, and important in turn for high insulating properties. Unfortunately the last traces of water are very difficult to remove. In fact, it has been said that with continued elevation of temperature all the way to complete destruction or reduction of the paper fiber into powder, water continues to pass off. Thus if the temperature rise must stop at 110 degrees centigrade as shown by F. M. Clark's acidity values and their influence on other properties, the retention of substantial amounts of water in the paper fibers must be recognized. Commonly it has been supposed that the chief function of paper in impregnated paper insulation, as related to the electric stress, is its action as an inert barrier to ionic motion in the oil. If a highly refined oil having low free ion content is used, impregnation causes little addition to the power factor and loss values of the unimpregnated dry paper. Loss values, however, are very sensitive to the ionic content of the oil. If this is high, it is correspondingly reflected in the value of loss after impregnation.

Obviously the free ion content of the oil may increase after impregnation. One common cause is oxidation; another, gaseous ionization. Now in F. M. Clark's results there is still another important possible cause in the liberation of acid products from the paper. In the writer's opinion the increases in power factor shown in figure 9 are due principally to the contamination of the oil by the acid products or by residual water, thus increasing its ionic content, conductivity, and loss, rather than to any appreciable structural change or loss of barrier action of the paper.

Although it is disquieting to think that the paper is not completely inert, and that it contains elements which may cause deterioration under high temperature and high stress, it is also reassuring that with proper design and care in assembly and service, impregnated paper insulation retains its high qualities up to very high values of stress, and at temperatures which usually introduce other limitations.

E. W. Greenfield (Anaconda Wire and Cable Co., Hastings-on-Hudson, N. Y.): The author has presented the results of a comprehensive work on a subject which is of extreme importance to the electrical art in general. Paper plays such an outstanding part in our high voltage systems that it is safe to say without its development as insulation and specialized technique of application our power generation and distribution systems would have been unable to make their great advancements.

In this paper the author draws conclusions concerning the chemical breakdown of paper as a result of heating, and he bases these conclusions upon the measured progressive changes in certain chemical, physical, and electrical properties of a representative type of cellulose paper.

Since these important conclusions rest upon the measurement of fairly small variations of the properties investigated, it is regrettable that no mention has been made in the paper concerning the probable accuracy of such measurements. For example, in the acidity determinations of tables I and II and figure 2 of the paper, acidity measurements are given to 0.01 milligram, yet for presumably identical conditions there is shown a variation of 10 times this value of acidity. Figure 2 of the paper shows the unheated test and the 48-hour treatment at 110 degrees centigrade to yield acidity values of +0.04 or +0.05. Table II of the paper, under similar conditions, shows values of acidity that are −0.08 and −0.06, respectively. Is this large variation due to the inaccuracy of acidity determinations, or is it due to a normal variation in response of the paper used? In this connection it is surprising how small is the recorded difference between the amount of acidity formed in atmosphere and in high vacuum. It has been felt generally that chemical deterioration at elevated temperatures necessarily is much retarded if the dielectric is kept under vacuum. F. M. Clark's results, however, do not indicate such an assurance.

The data shown in figures 9 and 10 of the paper, giving the influence of thermal effects on dielectric loss, are not quite clear. It is unfortunate that power factor measurements were not made on the paper alone, so that the influence of the oil could be accounted for. As it is, inferences other than those the author suggests may be drawn from figure 9. The exposure to higher temperatures causes an increased oil absorption of the paper which increases the power factor, although at the same time the additional removal of moisture should tend to decrease the power factor. As a matter of fact, if figure 9 of the paper is replotted, using as abscissa oil absorption values obtained from figure 1, a virtually linear relation results. This may be seen in figure 1 of this discussion. The heavy dots indicate the deviation from linearity. Again referring to figure 10 of the paper, many experiments have indicated that the increasing power factor of impregnated paper beyond 50 or 60 degrees centigrade is due principally to the oil and not to the paper; hence, it seems that a thorough analysis of the power factor phenomena would require an investigation of first, the effect on power factor of dry paper as it is exposed to various thermal conditions; second, the power factor of the saturant over a range of temperature, and finally the power factor of the combination oil and paper over a temperature range for each separately treated paper.

In this regard the question of power factor accuracy also is important. For example, it is seen that between the power factor values of samples under apparently

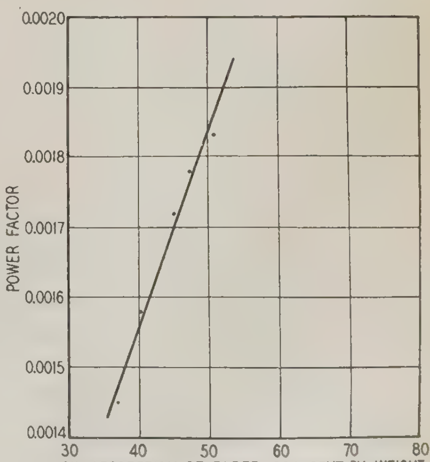


Fig. 1. Power factor of impregnated paper as a function of oil absorption of the paper

identical treating and testing conditions of figures 9 and 10 of the paper, there is almost as large a variation as is the whole power factor argument for figure 9. Are these variations due to power factor inaccuracy or sample variation? If the latter is true, the results shown in figure 9 just referred to are in doubt, since each point must represent a different sample. It is also noted that comparison of the table given on page 1094 (Elec. Engg., October 1935) and figure 9 of the paper would indicate that the power factor of the dry paper is larger than that of the oil impregnated paper under the same test conditions. In the writer's experience with wood pulp and manila paper dry paper has always shown a larger dielectric loss at the same temperature when impregnated with oil.

The result on dielectric strength as presented in figure 12 of the paper are indeed significant. There appears to be a very definite decrease in dielectric strength of the impregnated paper after exposure to progressively more severe thermal conditions. Whether this deterioration is due to breakdown of the properties of the oil alone or the combinations of temperature and increasing catalytic action of the paper is not clear. An interesting attempt at explanation would be to extract all the oil from a severely treated sample, redry the paper, impregnate with fresh oil, and determine if the breakdown value approaches that of the original sample before heat treatment.

The life test results presented in figure 14 of the paper show a power factor trend which many of us have observed during accelerated life testing of impregnated paper insulation. It seems that the rate of power factor rise is not so much influenced by the overall temperature of the insulation bath, but more so by particular isolated spots where the stress has caused ionization and, probably, local heating. For example, very similar increases in power factor with stress over life testing periods have been observed at a much lower bath temperature (40 degrees centigrade) than those of F. M. Clark's tests. J. B. Whitehead showed many such curves in his paper "Life of Impregnated Paper" (A.I.E.E. Trans., v. 52, Sept. 1933, p. 1004–12). It should be pointed out here that the stresses used during both of these life test observations are far in excess of those pertaining to impregnated paper insulation commercial practice.

The outstanding conclusion gathered from Clark's paper is that care must be exercised in considering the commercial operation of paper insulation at higher temperatures than those of present practice. This thought is worthy of serious attention.

Herman Halperin (Commonwealth Edison Co., Chicago, Ill.): F. M. Clark's paper is to be welcomed on account of its stimulating character in calling attention to the possibility of chemical deterioration of paper in electrical insulation. Experience in recent years with oil filled cables particularly, and with all types of insulation in general has emphasized the importance of the chemical side of the aging problem of insulation in service. The chemical aspect of oil deterioration has received increased attention in recent years. The chemical study of paper also should receive more attention. There are, moreover, some indications of the need for fuller control of the paper used in impregnated insulation. The author's work must be considered an important step in these directions.

The problem of paper research appears to be threefold:

1. Stability and its limitations of cellulose.
2. Stability of normal impurities in paper.
3. Effect upon the oil of impurities and deterioration products of the paper.

The author has attacked the first point of this program, and substantial benefit may be expected from an investigation of the other 2 points.

The temperature limitations for safe operation are extremely important, not only from a technical standpoint, but also from an economic standpoint. Short overloads occasionally become necessary in service. It may be more economical to subject the cables to such infrequent overloads than to install sufficient reserve capacity as long as the loss due to decreased life of the few lengths of cable affected by the overloads is below the cost for installing reserve capacity. Data like those presented by F. M. Clark are vital for an intelligent solution of this question.

In general, the author's data seem to indicate that serious deterioration of paper does not occur below 120 degrees centigrade. This is well above the temperature considered safe for impregnated paper insulation, and paper would, therefore, appear to impose no limitation upon the operation of cable insulation.

In this connection the statements that "chemical changes may result from prolonged exposure to almost any temperature" and that "longer periods of treatment at lower temperatures must be expected to produce similar chemical changes" seem to be important. It would be very desirable to have data on the rate of deterioration for temperatures lower than 110 degrees centigrade, which was in general the lower limit in these investigations, in order to determine at what temperature the deterioration of paper becomes of practical importance. It is true that temperatures as low as 80 to 90 degrees centigrade caused a decrease in mechanical strength, but this change is probably more due to loss of water than to an actual chemical deterioration. The power factor of impregnated paper showed some increase in a life test at from 95 to 100 degrees centigrade and 425 to 850 volts per mil, but it is not evident that this increase was caused by overheating of the paper and not by changes in the oil ionization in residual gas pockets at the very high stresses.

The statement that "cellulose insulation can be operated at temperatures higher than 50 degrees centigrade under conditions that reduce to a minimum the possibility of spot thermal concentration" seems to imply that operation above 50 degrees centigrade is hazardous. This statement is made after pointing out that the power factor may increase rapidly with temperature above 40 degrees centigrade. Modern high voltage cable insulations frequently show practically constant power factors between room temperature and 70 degrees centigrade, and considerable operating experience does not disclose any substantial harmful effects of operating at 60, 70, or 80 degrees centigrade.

Figure 1 of the paper is interesting, since it shows that oil absorption increases with increasing acidity of the paper. This result seems to indicate one of 2 possibilities: the formation of acidity by heat treatment produced a greater affinity between oil and cellulose, that is, better wetting, or the free space in the paper was increased by the treatment, possibly by evaporation of moisture and volatile deterioration products. Does the author have any information on these theories?

The statement that the paper shown in the author's figure 3 was placed in an atmosphere of pure hydrogen in order to eliminate carbonization under corona discharge is not clear. It appears that carbonization can occur also in the absence of oxygen. In thermal failures the insulation is considerably carbonized, probably without sufficient oxygen for oxidation. It seems also that ionization could produce carbon designs without the presence of oxygen.

It is shown in figure 4 of the paper that after a period of test at 175 degrees centigrade, gassing continued at a decreased rate for 11 hours and the conclusion is drawn that "cellulose insulation once severely overheated is not suited for further successful use." Continuation of the tests for longer periods would have been of interest to determine whether a recovery occurs with time. It is quite possible that a deteriorating process which is started at 175 degrees centigrade is brought to completion at 130 degrees centigrade, but that it may then die down.

F. M. Clark: The comments concerning the interpretation and importance of the data presented in the paper are appreciated. Considerable attention has been given to the question of the stability of oil when it is used as an impregnant for cellulose insulation as part of high voltage technique. It is hoped that the data presented will indicate that paper insulation itself cannot be considered as wholly stable and reliable. The acid products formed from paper, even in the absence of oxygen under what might be termed destructive distillation conditions, may play in important part in determining the usefulness of the oil impregnating dielectric.

In any chemical study of cellulose it must be remembered that many of the analytical tests, such as that of acid determination, are subject to considerable technical and personal variation. Although no basis can be held for the absolute accuracy of the test results reported, it is believed that the relationship established is of value, the data having been obtained by the same operator without variation in the test method.

J. B. Whitehead correctly points out that the paper calls attention to another source of ionization in the oil impregnated paper dielectric; namely, that of acid products derived from the paper itself. With some types and grades of paper this effect may assume an importance not previously recognized. It is to be suggested that this contribution, coupled with the fact that the ionic materials formed are corrosive in nature and form only with a simultaneous mechanical weakening of the cellulose, produces an effect which must not be ignored if successful dielectric behavior is to be obtained.

The power factor-temperature relation for

impregnated paper is dependent on a variety of conditions, and of these conditions the character of the impregnating liquid is one of the most important. It is true, as Herman Halperin points out, that some impregnated insulations have the minimum power factor at temperatures in such a range that marked increase in power factor from 25 degrees centigrade to 70 degrees centigrade is not observed. It is still true, however, that cellulose insulation can be operated at high temperature only under conditions which reduce the danger of hot spot concentration. One important condition is the power factor-temperature relation referred to by Halperin.

Perhaps Halperin's reference to figure 3 of the paper demands explanation. The writer is familiar with the "tree" designs and other evidences of carbonization of the cellulose frequently observed in cable failures. In the experiments referred to in the paper, when air or other oxygenic atmosphere was used, the cellulose showed evidence of carbonization, with a distinct black carbon formation. When, however, a nonoxygenic atmosphere was used, especially an atmosphere of hydrogen, there was no evidence of carbonization or black spot formation. The paper merely disintegrated mechanically until finally a gray colored dust remained. From such experiments it may be doubted that the formation of "tree" designs frequently observed in cables can be obtained in an oxygen-free condition.

The mechanical tests on the cellulose insulation were made only after the cellulose had been allowed to stand for at least 24 hours under the humidity conditions applying for the test.

Resolution of Surges Into Multivelocity Components

Discussion and author's closure of a paper by L. V. Bewley published in the November 1935 issue, pages 1199–1203, and presented for oral discussion at the power transmission session of the winter convention, New York, N. Y., January 29, 1936.

Ernst Weber (Polytechnic Institute of Brooklyn, Brooklyn, N. Y.): L. V. Bewley's paper is most interesting as a true engineering solution of a field problem which is very complex and difficult to solve. In dealing with traveling waves on transmission lines it is commonly assumed that the use of the stationary values of distributed inductance and capacitance leads at least to approximate results. These 2 field parameters are defined, however, by the 2 relations

$$\frac{1}{2}\,LI^2 = \frac{1}{2}\iiint HB\,dt \qquad (1)$$

$$\frac{1}{2}\frac{Q^2}{C} = \frac{1}{2}\iiint ED\,dt \qquad (2)$$

It is obvious that under transient conditions as presented by traveling waves the integration of the field vectors over the entire space occupied by the electromagnetic field will give results depending upon the time, and will be quite different from the steady state values of L and C. If, therefore, the common theory of traveling waves is to be applied, the parameters L and C should be chosen so as to take into account the field variation. This leads to nonlinear differential equations in the simplest case and therefore is very difficult to solve. The author, utilizing some experimental results and employing fine physical judgment, assumed equivalent and constant values for these parameters L and C, thus obtaining a modified solution of the traveling wave theory, with the most important result of multivelocity waves. It is quite obvious that the solution cannot be a rigid one; however, it should represent, if the parameters L and C are chosen properly, a very good approximation for engineering purposes. The paper, which shows the practical application of the theory in connection with oscillograms obtained on a test line, is therefore a beautiful demonstration of the engineering point of view in solving very difficult field problems by means of equivalent or modified field parameters. It will remain for future treatment to obtain from the rigorous application of the field theory a justification for the modification of the two parameters L and C and to show that the equivalent values as chosen by the author are in the right direction and approximately correct for the initial time interval.

L. V. Bewley: Ernst Weber points out in his discussion that our conventional concept of a transmission line as having uniform inductance and capacitance per unit length is not exact from a strictly mathematical point of view, but that these coefficients must of necessity vary with the length and shape of the traveling wave. It is known, however, that by assuming average values for these coefficients, conventional theory leads to quite accurate engineering results. Nevertheless, it is highly desirable that the problem of traveling waves on a multiconductor system over a resistive earth be attacked from the rigorous point of view of electromagnetic theory. It is to be hoped that Weber will try his hand at this interesting and practical problem, and at some future time produce a complete solution based on Maxwell's equations.

Lightning Investigations on a Distribution System

Discussion and authors' closure of a paper by Herman Halperin and E. H. Grosser published in the January 1936 issue, pages 63–70, and presented for oral discussion at the protective devices session of the winter convention, New York, N. Y., January 30, 1936.

R. G. Warner (Yale University, New Haven, Conn.): The writer has been interested in the service improvements reported with interconnected grounds and has 2 comments or queries regarding these. One utility company has many interconnections and is enthusiastic about the results. On the contrary, another utility company, in Connecticut, wonders whether part of the improvement in operating performance may not be due to closer supervision of transformer installations and of lower resistance grounds. This particular system has about 950 transformer installations, 700 transformers connected to a 3-phase 4-wire 4,150-volt system, and about 250 transformers connected to a 4,800 volt delta system.

All transformer cases are grounded. About 5 years ago transformers were fused for short circuit conditions, and where there is no public water supply system, the secondary neutral conductor was grounded on each side of the transformer. The transformer loads are checked to prevent overloads. The improvement in fuse operations may be noted as follows:

	1931	1932	1933	1934
4 wire system	90	14	5	6
Delta system	No data	12	7	4

This improvement is without interconnection of grounds.

In connection with this paper the writer notes a 25 per cent increase in meter burnouts, although another report ("Distribution Transformer Lightning Protection," L. G. Smith. Elec. Engg., v. 55, Jan. 1936, p. 47–53) shows a decrease. Some utility companies have been investigating meter inaccuracy after lightning storms that apparently is due to surge current sufficient to affect the damping magnets, but not enough to burn out the meter. If more meters are burned out with the discharge of lightning partly through the secondary grounds, can anyone state the effect interconnection may have on the accuracy of the connected watthour meters?

C. M. Foust (General Electric Co., Schenectady, N. Y.): It might be appropriate to mention that the important investigational work summarized in this paper and a paper by K. B. McEachron and W. A. McMorris ("Discharge Currents in Lightning Arresters," Elec. Engg., v. 55, Dec. 1935, p. 1395–99), has been aided by the recent introduction of surge voltage recorders of the Lichtenberg figure type and surge current ammeters of the magnetic link type.

The surge voltage recorder used by Halperin and Grosser records crest voltages in terms of the diameters of positive polarity photographic Lichtenberg figures. A corresponding negative polarity figure also is obtained for each surge. As the negative figures vary in size and character with wave front as well as crest voltage, some idea of wave steepness can be obtained. Again as the individual streamers of a positive figure produced by a unidirectional polarity surge never cross, it is possible to draw a fairly definite conclusion of the number of surges recorded on a single film. A single surge produces a positive figure without crossed streamers, a superposition of 2 or 3 surges gives an increasing number of streamer crossings. With more than 3 superimposed figures, the interpretation of the exact number of surges applied on a stationary film is not possible. Also, it is not possible to distinguish definitely between repeated surges of varying polarities and a single oscillatory surge of several half cycles. How-

ever, on the basis of general consistency of voltage values at several measurement points and locations as shown in figures 3 and 4 of the paper, it appears reasonable to assume such a co-ordination of values as given.

The measurement of crest values of surge currents described in both this paper and the paper by McEachron and McMorris previously referred to were made with the surge crest ammeter-magnetic link arrangement for unidirectional polarity and oscillatory surges. This measurement apparatus has been described in a previous paper ("Direct Measurement of Surge Currents," C. M. Foust and J. F. Henderson, ELEC. ENGG., v. 54, April 1935, p. 373–78). Where it can be assumed that the maximum current through and maximum voltage across, a lightning arrester are simultaneous, the use of the surge voltage recorder and the surge crest ammeter permits a field measurement of the discharge impedance of the arrester.

K. B. McEachron (General Electric Co., Pittsfield, Mass.): It is gratifying to note the general improvement with respect to transformer burnouts as a result of the interconnection of the primary lightning arrester ground and the secondary neutral, as shown in this paper. The lightning performance of the distribution system of the Commonwealth Edison Company is better known through the papers of D. W. Roper and his associates than is any other system. Therefore, considerable confidence can be placed in the operating results now being reported.

The writer is inclined to disagree, however, with the authors' discussion of their conclusion 3, relative to the position of the tank with reference to the primary and secondary potentials during a lightning storm. It is true that with interconnection, without the tank being tied in, under special conditions voltages in excess of the arrester potential, or potential between primary and secondary, may appear between the windings and the tank. The potential of an insulated tank, in the case of a traveling wave arriving over either the primary or secondary winding, is determined by the capacities between the windings and the tank, and between the tank and ground.

Tests under these conditions have shown (see "Lightning Protection for Distribution Transformers, K. B. McEachron and L. Saxon, A.I.E.E. TRANS., v. 51, March 1932, p. 239–44) that the tank potential may be expected to assume a value differing by about 10 per cent from that of the secondary winding, assuming that the tank is well insulated from ground. If the arrester holds the potential to e volts, and it is assumed that the potential between the primary wire over which the impulse is arriving and true earth is E volts at the time of arrester discharge, the tank potential above earth would be $E-0.9e$ and the potential at the secondary neutral would be $E-e$. If the tank should be grounded to a separate ground not connected to the secondary neutral, however, the impulse potential across the primary bushings would be E volts, and $E-e$ volts across the secondary bushings. If the primary and secondary bushings had the same flashover potential, the primary bushing would flash over first if the potential E were high enough, elevating the tank potential to whatever potential would result from the flow of current from the tank through the resistance of its earth connection. The resulting tank potential difference with respect to a secondary phase wire might be high enough to flash over a secondary bushing also. Flashover across both primary bushings might also result in some cases. In any event, a blown fuse would be likely to result, even though the potential difference between primary and secondary were held to a low value by the interconnected arrester. For this to happen, the primary and secondary bushings need to have approximately the same flashover value. As a rule, most distribution transformers have secondary bushings of which the flashover value is much less than the flashover of the primary bushings, which means that before the primary bushing reaches its flashover value, the secondary bushing will have flashed over, thus bringing the tank potential to the secondary neutral potential of $E-e$ volts, with the result that the potential across the primary bushing would not exceed the arrester volts plus any drop in the leads. Thus, an outage would be prevented.

Modern transformers are provided with gapped secondary neutral bushings, so that the tank potential can get no further from the secondary potential than the flashover of this gap, which is low compared to the primary bushing flashover. This practice confines the flashover on the secondary for impulses originating on the primary to the secondary neutral wire, which is desirable from the point of view of danger to customers' equipment.

The data shown in figures 3 and 4 of the paper do not indicate potentials released from bound charges, because the polarity is negative in almost every case. Data obtained by W. W. Lewis and C. M. Foust (see "Lightning Investigations on 3 Transmission Lines," ELEC. ENGG., v. 54, Sept. 1935, p. 934–42) in this country, and Gruenwald in Germany ("Die Messung Von Blitzstromstarken on Blitzableitern Und Freileitungsmasten," H. Gruenwald, *E. T. Z.*, May 24 and 31, 1934, p. 505 and 536), indicate that the direct stroke is predominantly negative, somewhat less than 10 per cent being positive. This is also borne out by other data (see "Discharge Currents in Distribution Arresters," K. B. McEachron and W. A. McMorris, ELEC. ENGG., v. 54, Dec. 1935, p. 1395–99) which show that for currents of the order of 5,000 amperes or more, the positive records are 10 per cent or less of negative. Thus, it appears doubtful that many of the records of figures 3 and 4 of the paper could have been the result of the release of bound charges, assuming that the polarity indication is correct.

The suggested mechanism does not seem likely, by which the charges cannot leak off the transformer tank rapidly enough to prevent the tank from remaining at or near ground potential, although the line conductors are elevated as the result of the release of bound charge. To get some idea of the time required for charges to break from the transformer tank to ground, assume a tank capacitance to ground of 10 micromicrofarads and a resistance to ground of 100 megohms. The time constant of the circuit will then be 0.001 second, which is very short compared with the time required to charge clouds, or for clouds to drift over the line. In most cases, a ground wire attached to a ground rod will be but a few inches from the tank, and certainly the leakage resistance will not be high when the pole is wet. Therefore, it seems doubtful that the results shown in figures 3 and 4 of the paper are usually the result of the release of ground charges.

As a rule, the potential of the transformer case, from the point of view of leakage to ground, probably is controlled by the presence of the ground wire interconnected to the lightning arrester and the secondary neutral. However, cases may exist in which a foreign ground may be in such a position as to control the potential of the transformer case, which creates a situation that explains excessive primary-to-tank potentials. In those cases in which such a foreign ground does not exist, it will be necessary to look further for an adequate explanation.

It would be interesting if the authors could separate the transformer failure and fuse blowing record, where the arresters are not on the same pole, so that some idea could be obtained of the relative performance compared to those cases where the protection is mounted on the same pole.

B. D. Holley (Commonwealth Edison Co., Chicago, Ill.): The 60 cycle tests of 3 kv lightning arresters were developed by the testing department of the company with which the writer is associated primarily as an economical routine determination of the serviceability of used arresters. The tests are used also on new arresters to insure uniform and suitable 60 cycle characteristics. The tests are not intended to replace the more accurate methods of determining arrester performance under surge conditions. They do indicate with reasonable accuracy, however, changes in the internal condition sufficient to make the arrester unsatisfactory for further service.

In developing the tests, measurements made on a number of new arresters of various types indicated that each type of arrester has uniform 60 cycle characteristics.

On this basis a change in the internal condition is indicated by characteristics that are appreciably different from those in new arresters of the same type. This relationship between 60 cycle characteristics and internal condition was verified by inspection of a great many used arresters. Subsequent verification has been obtained by inspection of the arresters rejected in the 60 cycle tests. The extent of internal change in the used arresters was found to follow in general the change in 60 cycle characteristics, and the 60 cycle test limits were set to reject those arresters in which the change was sufficient to reduce appreciably their effective life, or to make their operation unsatisfactory or uncertain. The minimum breakdown voltage limit was set to reject those arresters unlikely to recover above system voltage after breakdown, and the maximum breakdown voltage was set to reject those arresters likely to have excessive voltages under surge conditions.

The allowable limit of the leakage current of the arresters, measured at an operating voltage, of 2,300 was set to reject those arresters in which considerable corrosion or change was indicated. Leakage currents measured in tests of used arresters have

ranged from that of new arresters to a completely short-circuited condition, indicating progressive changes in the internal condition. The leakage current limit was set to pass arresters in good or very slightly corroded condition and to reject those in which the corrosion had progressed to an undesirable degree. Series gap type arresters with high leakage currents are rejected not only because of corrosion but also because the characteristic element in service will be subjected continuously to voltage with probable eventual deterioration.

Inspection of rejected arresters has revealed conditions that could not in any way be determined from the external appearance. Various stages of corrosion have been found, ranging from slight corrosion to complete disintegration. Metal parts have been found broken, burned, and pitted, and characteristic elements were broken, decomposed, and radically changed in appearance and condition.

The 60 cycle tests by the company with which the writer is connected have provided economically a stock of serviceable used arresters.

At the present time all tests are made in the testing department laboratory; however, the equipment easily could be put into portable form for test on arresters in use on the distribution system.

L. G. Smith (Consolidated Gas, Electric Light, and Power Company of Baltimore, Md.): The decrease in rates of lightning trouble on transformers that have lightning arrester grounds interconnected with the secondary neutral, as noted for the Chicago system, agrees almost exactly with the data that have been combined from some 38 operating companies so far as primary fuses blown and transformer winding failures are concerned. A reverse tendency is noted for lightning arrester failures, however, for the combined data show a 34 per cent decrease in lightning arrester failures with interconnection as compared with Chicago's 47 per cent increase.

The experience of the authors, in which the transformer bank potential remains near ground potential, constitutes a real reason for connecting the transformer case to the interconnection through a gap.

The data the authors have been collecting with surge recorders to determine surge currents and voltage distribution throughout the system of conductors, lightning arrester, transformer and secondary should partly explain what happens when a surge encounters a transformer pole, and should be of real assistance in applying protective schemes to reduce lighting troubles on distribution systems. The 50 records of surge potentials, although not sufficient in number to be conclusive, lead to some very interesting points, which the authors have presented. One point of interest is that about $^1/_2$ of the surges recorded are 10 kv or less. Another point of interest is that the ratio of surges encountered to primary fuses blown apparently is about 200 to 1. This seems to indicate that lightning protection equipment is effective. The rate of troubles on the Chicago system is much lower than that for other systems having more exposed transformer installations, however, and these ratios probably cannot be generally applied. The authors are to be congratulated for the collection of data of this type. It is hoped that this investigation will be continued to include a large number of records.

In reference to the testing of lightning arresters, the writer has found it essential to test all arresters, not only those returned from lines but also the new ones received from the factory. The deterioration of lightning arresters, reported by the authors, is characteristic of all arresters except those made in the last few years. The trouble generally has been due to corrosion resulting from moisture in the gap assembly. Even a slight discharge causes the formation of nitrous oxide, which in the presence of moisture is converted to nitric acid, resulting in rapid corrosion of the gap. It is hoped that the present means of sealing the gap assemblies of lightning arresters will prove successful in preventing this trouble.

J. K. Hodnette (Westinghouse Elec. and Mfg. Co., Sharon, Pa.): The authors of this paper have collected and compiled some valuable data on the effects of lightning; they will be useful either to prove or disprove the validity of existing theories on lightning protection.

It is interesting to note that the effectiveness of the interconnection to prevent transformer failures and fuse outages is less than expected; in general, these factors were reduced 49 to 67 per cent, respectively, but one case of trouble was found for every 7 or 8 surges over 100 kv. This is explained largely by the fact that the transformer tank does not "float" or assume a potential between that of the high voltage and low voltage windings; instead, it remains near ground potential, causing a high voltage to exist between each of the windings and tank when the potentials of the windings rise above ground.

Several years ago the writer recognized this, and pointed out that it would be necessary to take the tank into the protection circuit and employ a balanced protection of the 3 insulations between windings and between each winding and tank. This idea, which is called 3 point protection, was used as the basis for the design of a self-contained, surge protected distribution transformer. The protective devices in this transformer are deionizing gaps connected between the high voltage winding and tank and a co-ordinated low voltage bushing with a selective gap to the neutral connected to limit the surge voltage on the insulation between low voltage winding and tank. Collectively, these devices limit to a safe value the surge potentials that can exist on any of the 3 insulations.

Thousands of these surge protected transformers have been in service during the past 4 lightning seasons. The effectiveness of this method of protection has been outstanding; winding failures have been reduced to a negligible fraction of a per cent, even for exposed rural areas. Balanced protection of the 3 insulations has become so well established that standard transformers may be obtained with secondary bushings reduced in flashover values in order to obtain balanced protection and thereby prevent winding failures and fuse outages when the tank potential fails to "float."

It is the writer's opinion that the lowering of the tank potential found by the authors is attributable to a leakage of the charge from the tank through the pole, guy wires, or other objects, instead of a failure of the tank to take a charge. The relatively high capacitance between the windings and tank compared with the capacitance between tank and earth would supply the necessary charge. To maintain the tank at ground potential it is necessary only to discharge the relatively small tank capacitance, which can be effected through a relatively high resistance circuit such as a wet pole. Many more troubles occur when the surge voltage is in excess of 100 kv than when it is lower than 100 kv. This high rate of failure is caused, no doubt, by the protective circuit permitting excess voltage on some part of the transformer insulation instead of a progressive deterioration of the insulation to the point at which failure occurs.

As a part of the development of the surge protected transformer, a study was made of the effect of repeated surges on transformer insulation. As many as 5,000 surges, ranging in magnitude from 50 kv to 1,000 kv, were impressed on a single transformer equipped with 3 point protection with deionizing gaps. Careful examination and test showed that no reduction of the 60 cycle or surge strength of the insulation resulted from these experiences, and no evidence of stress on the insulation could be found.

L. R. Ludwig and **A. M. Opsahl** (Westinghouse Elec. and Mfg. Co., East Pittsburgh, Pa.): In the paper by Herman Halperin and E. H. Grosser, the notation differs from that of L. G. Smith, and all special forms of protective circuits are classed simply as interconnection. The results the authors have obtained by measuring line-to-ground, tank-to-ground, and neutral-to-ground potentials are very interesting, and the fact that the tank generally has a potential much nearer ground potential than does either the line or the secondary neutral indicates the need and desirability of either a direct or gapped connection to the tank from the secondary neutral. The authors' measurements across the interconnection leads are a definite indication that these leads must be kept as short as possible in order to provide adequate transformer protection, particularly at the higher surge currents.

The authors have found an increase in watt-hour meter failures with the interconnection. Although the failures involved only 3 or 4 out of each 10,000 meters installed, it would be of interest to know whether the meter failures occurred on secondary circuits of transformers where bushing flashovers or transformer failures had passed primary fault current into the secondary circuit. If such is not the case, it appears that surge flashovers in the meters continue in power arcs. There may be some indication that 110 volt meters are less subject to such failures than 220 volt or 440 volt meters.

T. H. Haines and **W. B. Elmer** (Edison Electric Illuminating Co. of Boston, Mass.): This excellent paper gives results of inquiry into several new phases of the lightning problem. In connection with part of conclusion number 5 of this paper, the writers believe that the reduction in troubles on the system

of the company with which they are associated by the application of lightning arresters during the past 10 years has been equalled or exceeded by the reduction attributable to modernization of the transformers.

The writers agree with conclusion number 6, and also interconnect lightning arrester grounds with cable sheaths wherever possible, on transmission as well as distribution lines.

In the first paragraph of page 66 of the paper, an explanation different from the one the writers have suggested in their discussion of L. G. Smith's paper ("Distribution Transformer Lightning Practice," Elec. Engg., v. 55, Jan. 1936, p. 47–53) for the fact that transformer tanks are near to ground potential than is either set of leads. This explanation depends upon high pole resistance to ground; the writers' explanation depends upon low resistance. Which is correct? The eighth surge record in figure 3 of the paper shows an instance in which the transformer tank assumed a potential intermediate between the coil potentials. If the writers' theory is correct, this pole resistance should be higher than the others; if Halperin and Grosser's is correct, it should be lower.

It is of interest to us to note that the a-c test method employed in checking second-hand arresters is one the writers used several years ago. Corrosion of the metal interior parts of the arresters was found by means of these tests.

Herman Halperin and E. H. Grosser: In attempting to account for the finding of reduced transformer tank potentials under lightning surge conditions, considerable thought was given to the construction of a theory that would comply with all known factors. The theory of conduction or leakage over wet pole surfaces, suggested by T. H. Haines and W. B. Elmer, was rejected early in the study in view of the evidence that surge sparkover along wood surfaces is unaffected by moisture. The later theory indicated in the paper appeared more logical. It was recognized that the time constant of the tank-to-ground circuit might be fairly small under some conditions although not as low as 0.001 second as given by K. B. McEachron. With interconnection, the effective tank-to-ground capacitance is that capacitance between the core and secondary winding. For typical distribution transformers, this varies from about 700 to 2,000 micromicrofarads. With a pole resistance of 100 megohms, the time constant of the circuit is about 0.1 or 0.2 second. This is not negligible in comparison with the usual time required for cloud charging.

The writers cannot agree that the bound charge theory should be rejected on McEachron's claim that figures 3 and 4 of the paper show a preponderance of negative records, indicating a probability of their origin as mild direct strokes or side flashes. Examination of these diagrams shows that, in addition to 4 cases showing both polarities, the primary phase wire was positive in 8 cases and negative in only 6. For all the data obtained in the 2 year investigation of tank potentials, 20 showed positive primary phase potentials, and 14 were negative. Argument on the basis of surge polarity thus tends to support, rather than disprove, the bound charge theory.

As to the possibility of control of tank potential by foreign grounds, this might be possible on some systems. For Chicago installations, however, foreign grounds practically never are encountered near the transformer tank. Steel telephone messengers are fastened to the pole several feet below the transformer, and guy wires always are insulated. The only ground that could control tank potential to an appreciable extent is the arrester grounding lead that passes down the pole within a foot or so of the tank, but this is interconnected with the secondary neutral main, and would tend to hold the tank potential near the potential of the secondary winding.

The mechanism resulting in lowered tank potentials suggested by J. K. Hodnette is in the final analysis practically identical with our own theory. Whether the tank fails to take a charge or whether the unbound charge leaks off the tank before discharge appears relatively unimportant so long as it is conceded that some reduction in charge takes place. The writers plan to investigate further the theory of low tank potentials, and similar work by others would be desirable.

In regard to McEachron's request for data showing the effect of arrester location on the protection afforded the transformer, recent studies have indicated that on our system such an effect can be anticipated only for the interconnection, as with "normal" arrester protection the locations of various secondary grounds are too erratic to permit analysis. For stud type transformers with interconnections, the rate of lightning troubles, according to our data, was somewhat larger where the arrester was not on the same pole with the transformer than where they were installed together.

A question was raised by R. G. Warner as to whether some of the improvements noted with interconnection may not have been due to other system improvements and better maintenance of grounds. The superior performance of the interconnection on this system was studied for both protective schemes in use simultaneously on the system, thus yielding data that are strictly comparable.

Some points of general interest appear in the discussion on meter failures. Warner refers to the effect of lightning disturbances on the accuracy of watt-hour meters. The writers have heard that this might occur in some cases, but have no information on the subject. L. R. Ludwig and A. M. Opsahl request data on meter failures that are coincident with troubles at transformers on the same secondary circuits. The writers' studies showed that less than $^1/_{20}$ of all meter failures caused by lightning occurred when other equipment in the same block was damaged by lightning. Only 8 per cent of the transformer, fuse, and arrester failures caused by lightning involved meter failures. It seems probable that the ratio of surge flashovers in meters to meter failures is very high, in view of the improbability of service voltages supporting a power arc except under the most favorable conditions.

C. M. Foust suggests the simultaneous measurement of arrester surge voltage and current to determine the discharge impedance of the arrester. It is planned to attempt such measurements in the future.

The writers wish to express appreciation to B. D. Holley for describing in much greater detail than space permitted in the paper the procedure followed in conducting 60 cycle tests on arresters. It is gratifying to note the confirmation of this test method as mentioned by Smith, Haines, and Elmer.

Corona Losses at 230 Kv With One Conductor Grounded

Discussion of a paper by J. S. Carroll and D. M. Simmons published in the August 1935 issue, pages 846–47, and presented for oral discussion at the power transmission session of the winter convention, New York, N. Y., January 29, 1936.

W. W. Lewis (General Electric Co., Schenectady, N. Y.): The test results given in this paper are very interesting and should be taken into account, as the authors suggest, in the consideration of Petersen coils.

Although there is a tremendous difference, as disclosed by the tests, between the corona loss for a normal 3 phase line and one with a conductor grounded, still at the operating voltage of 230 kv the loss may not be a serious factor. Even at 4,000 feet altitude the in-phase current will be only about 3 amperes per 100 miles with the middle conductor grounded, from figure 3, and actually it would be somewhat less on account of the voltage drop along the line.

It is interesting to see the values of the actual residual current that has been measured on lines equipped with Petersen coils, as given in the following table:

Company	Voltage	Miles	Amperes Residual	Amperes per 100 Miles
Alabama Power Co.[1,2]	44,000	93	2.4	2.6
Consumers Power Co.[3]	140,000	226	45.0	19.9
Central Main Power Co.	33,000	560	23.0	4.1

All of these coils have operated satisfactorily. In the case of the Consumers Power Company, with a residual current of about 20 amperes per 100 miles, about 70 per cent of all faults have been interrupted without switch operation in the 4 years since the coils were installed.[3,4] The Central Maine coil was installed about August 1, 1935, and in the 3 months following it operated 17 times with only one oil circuit breaker operation.

If the in-phase current should become a serious factor in the operation of Petersen coils there are several methods of neutralizing this current. One of these was described by J. R. Eaton in his discussion of a paper.[3]

References

1. The Neutral Grounding Reactor, W. W. Lewis, A.I.E.E Trans., v. 42, 1923, p. 417–34.

2. Operating Performance of a Petersen Earth Coil, J. M. Oliver and W. W. Eberhardt, A.I.E.E. Trans., v. 42, p. 435–45 and A.I.E.E. Trans., v. 45, 1926, p. 165–68.

3. Petersen Coil Tests on 140 Kv System, J. R. North and J. R. Eaton, Elec. Engg., v. 53, January 1934, p. 63–74 and Elec. Engg., v. 53, April 1934, p. 612–13.

4. The Petersen Coil, W. W. Lewis, *Gen. Elec. Rev.*, April 1935, p. 197–200.

Pilot Wire Relay Protection

Discussion and authors' closure of a paper by E. E. George and W. R. Brownlee published in the November 1935 issue, pages 1262–69, and presented for oral discussion at the protective devices session of the winter convention, New York, N. Y., January 30, 1936.

C. M. Longfield (State Electricity Commission of Victoria, Melbourne, Australia): The paper describes most clearly both the advantages of d-c pilot wire protective systems and the high degree of reliability that can be expected now from leased telephone circuits, if proper safeguards are employed. This latter fact should be of considerable interest to those in whose minds there may linger any doubts about the reliability of this form of protection.

Under "new principles" the authors make some statements that may be a little misleading. Protective schemes of the type under discussion were in operation before those described by the authors as having been installed in 1931 and 1932. The writer installed a lock-in system in Sydney, Australia, as early as 1928. This was applied to radial feeders only, but in the following year a ring main network was equipped with directional overload relays as the initiating relays. It is probable that directional systems were in service in England before 1931. The authors' inaccuracy probably is inadvertent, since the points now disclosed were mentioned by G. B. Dodds in the discussion of a previous paper ("Relay Systems Utilizing Communication Facilities," J. H. Neher, Elec. Engg., v. 52, March 1933, p. 162–68).

The authors quite correctly lay considerable stress upon the protection of the pilots against interference and over-voltage. The use of the neutralizing transformer is an ingenious method of overcoming a rise of ground potential. In this connection, it might be of interest to observe that the Post Office in Great Britain, from which telephone wires may be leased for this purpose, stipulates the use of an insulating arm on the locking relay capable of withstanding 15 kv or 30 kv momentarily, depending upon whether it is to be used in conjunction with power circuits operating at voltages below or above 33 kv.

There always has been a strong feeling against the use of continuously energized circuits as a means of supervision, although this is common practice in fire alarm circuits. In the original Sydney installation, to which reference has already been made, arrangements were made for the pilot circuits to be checked at every change in shift at attended substations. This was done by pressing a key that closed the locking circuit, in which was connected a red warning light. The light remained energized until it was shut off by the attendant. In a radial feeder system the red light acted as an indication of the operation of the lock-in relay, which naturally followed the opening of a circuit breaker in a remote, and perhaps unattended, substation.

Practice in England has been inclined to the use of telephone lines that normally would be operated for their original purpose. During fault clearance they are temporarily disconnected from the telephone instruments and utilized as protective pilots. It would be interesting to know the extent of such practices in America.

O. C. Traver (General Electric Co., Philadelphia, Pa.): The authors are to be commended for this worthy contribution to the protective art, and for their persistence in overcoming the obstacles confronted in their determination to reduce the number of undesirable interruptions in commercial pilot wire circuits. The automatic system they have developed to give an alarm in such an event is excellent, but the writer wonders to what extent other territories will be able to profit from the Tennessee experience and whether, in general, each power company will not need to work out its own individual problems with the local communication organization to a considerable extent.

Let no one think that the writer disapproves of the use of pilot wires. Where a reliable wire channel is available it certainly can have a proper place in the protective ranks.

Having decided on the use of a pilot, the decision as to whether to install carrier or a wire channel is purely one of economics. The longer lines demand carrier, and the very short ones demand wire. The dividing point between these is somewhat of a nuisance, because the result is subject to calculation, and may be checked by others.

Since the price of carrier and relay equipment is an important item of this calculation, the writer takes pleasure in stating that because in consistent belief in carrier protection, developments in this line have continued to a degree not in proportion to the depression period acceptance, and that the prospect of a considerable reduction in the price of these items is imminent. This again shortens the length of an economic wire pilot, and when operating company support is comparable to the value of this protection, further surprising changes in this length may be visualized.

This new development is not only lower in price but also is faster. It will make commercially available 1 cycle carrier protection, giving simultaneous tripping at both ends of the line in a time interval that is negligible.

The authors long have been in the front ranks of those who blaze the way to better relaying and the better service that follows to pay its cost. It might at first seem surprising, then, that they did not spend this energy in carrier channels, but without making any comparisons, the writer wishes to say that they have performed a signal service in worthy conquest and it is predicted that when they extend their attention to the longer lines they will just as enthusiastically enlist carrier protection. It probably will follow that when they are better acquainted with carrier on their longer lines they will be surprised to see for how short a line carrier pilot is economically indicated.

The writer cannot understand the reference to flashing of vacuum contact relays. It sounds as though the vacuum is poor.

The authors indicate that tapped lines can be protected with untapped metallic pilots if the tap load is not large enough to operate the initiating relays. The writer can agree on this only if "tap short circuit current" is substituted for "tap load."

C. H. Frier (Oklahoma Gas and Electric Company, Oklahoma City): The company with which the writer is connected has had considerable experience with pilot wire relaying during the past 6 years.

The writer is thoroughly in agreement with the idea that pilot wire relaying is an ideal system. It has, however, presented a difficult problem when applied to long transmission line sections.

All of the pilot wire relay installations on this system (see "Relaying With Two Pilot Wires," C. H. Frier, Elec. Engg., v. 50, Oct. 1931, p. 824–26) make use of leased wire telephone service for the pilot wire circuits. These circuits have given good performance, but they are rather expensive in operation because of the long leased wire connections involved, and for that reason their use was discontinued on the long sections of line, and instantaneous overcurrent relays were applied in the place of the pilot wire relaying (see "Instantaneous Overcurrent Relays for Distance Relaying," C. H. Frier, Elec. Engg., v. 54, Apr. 1935, p. 404–07).

Some outages were experienced on the leased wire circuits, but they rarely were coincident with transmission line faults; therefore, they did not interfere to any extent with the relay operations.

The company has retained 3 of the shortest of these pilot wire relayed sections, because of their importance. Of these sections, 2 are about 2 miles long and the other is 11 miles long. The 2 short sections have performed remarkably well. One of them is of open wire construction and is built close to some 66 kv lines, and the other is of lead covered cable throughout. The 11 mile section is of open wire construction and has continued to show good performance.

The supervisory system that was applied to the pilot wire relay system has been of invaluable aid in the operation of the system as well as in analyzing pilot wire relay operations, and it is believed to be an indispensable part of the system.

On long line sections momentary pilot wire outages due to carbon block protector operations during lightning storms coincident with a fault on the transmission system are potential causes of trouble. Considerable study is being given to the further use of relaying through pilot wire channels. It is believed that the use of neutralizing transformers is a solution for the lead sheathed pilot wire, but the application to open line construction still is unsolved.

J. H. Neher (Philadelphia Electric Co., Philadelphia, Pa.): In reference to a paper presented by the writer ("Relay Systems Utilizing Communication Networks," J. H. Neher, Elec. Engg., v. 52, March 1933, p. 162–68), the general reaction of the authors

seem to be that pilot wire protection utilizing telephone circuits is a fine idea if the telephone circuits perform in an entirely satisfactory manner. It is gratifying, therefore, to realize that the authors of this paper have, after extensive tests, come to the conclusion that telephone circuits can be made to fulfill this requirement. In the 4 years' experience of the company with which the writer is connected with protection of this type, 27 correct operations, one in correct tripping on a through fault, and 2 failures to trip on an internal fault have occurred. It is certain that 2 of these incorrect operations were due to defects in the directional relay system controlling the pilot wire and not to any fault of the pilot wire. It is believed also that the third incorrect operation falls in the same category. In fact, the writer is of the opinion that the weak link in the chain is not the pilot wire, but the directional relay system controlling it.

The authors are to be congratulated for developing the neutralizing transformers and thus eliminating one of the major obstacles encountered in the application of the d-c loop. The writer regrets that they have not told more about it.

The method described for supervising the circuit by using reverse polarity in the monitor system is interesting, but its necessity is doubtful. A short circuit or open circuit in the pilot wire can be detected just as well with a small current as with a large one. Why not use equal resistances at each end of the circuit, high enough to hold the monitoring current down to, say, 1 milliampere (far below the pickup value of the tripping relays) and then detect variation in the monitoring current at the battery end by means of a sensitive relay.

Somewhat complicated systems are described with the idea of permitting the pilot wire system to function on a tryback from one end. The simplest system, where it can be applied, is obtained by adding a contact on the circuit breaker closing button that will by-pass the directional relay system at that end directly into the trip circuit as long as the button is held in the closed position.

As the authors have pointed out, the pilot wire can be utilized for remote supervision as well. By using rectifier polarized relays a single pilot wire can be used for the protection of 2 parallel lines. Such an arrangement recently has been installed on the system of the company with which the writer is connected.

B. M. Jones (Duquesne Light Co., Pittsburgh, Pa.) and **L. C. Bell** (nonmember; Duquesne Light Co., Pittsburgh, Pa.): At the present time the company with which the writers are associated has several installations of a-c circulating pilot wire, but no installation using d-c single-channel metallic pilot wire circuits, to compare the directions of fault current at the 2 ends of a transmission line.

Among such d-c installations are 2 that were connected in the system during 1931, but during the first year there were numerous operations on them without any evidence of faults within the protected sections. The exact reason for these operations has not been determined; therefore, the protection was removed from service, since it supplemented another relay scheme. Plans have been under way, however, to revise the original schemes, using copper oxide rectifier units as suggested by the authors, to control the direct current path. The writers feel, that there is a weakness in the scheme described by the authors, however, and hesitate to use it because apparently it is subject to incorrect performance on simultaneous line-to-ground faults on different phases of different lines. Such faults appear to cause a reversal of polarity on some ground relays, which results in tripping failures in some locations and incorrect tripping in others. The plan of the system of the company with which the writers are connected, with numerous double-circuit pole lines, is such that this type of fault does occur on both 22 kv and 66 kv lines.

In order to prevent most of these incorrect performances, the phase and ground relays are being separated in the revised plan by using 2 telephone pairs instead of 1 pair. On this revised system the phase relays may clear a fault within the section, even though the ground relays might have reversed polarity. For simultaneous ground faults on different phases outside the section incorrect tripping will be prevented in case of reversed polarity of the ground relays at both ends. However, if the phase relation between the ground current and voltage is such as to reverse the polarity of the ground relay at only one end, incorrect tripping still will be obtained. It is expected that this latter situation will occur infrequently, and because the line remains energized at one end indicates that the transmission line itself is still energized and that the relay equipment is faulty.

The 2 modified installations are expected to be in service before the next lightning season, when valuable operating data should be obtained.

O. J. Huie (Southern Bell Telephone and Telegraph Co., Atlanta, Ga.): The authors have covered the subject so completely in their paper that there is little left to say. However, it may be helpful to emphasize a few points of particular interest to the telephone company.

In furnishing leased facilities it is the aim of the telephone company to provide suitable, adequate, and reliable service, and to throw about it such safeguards as will insure efficiency and continuity.

In pilot wire relay protection and other forms of supervisory service, continuity is of the highest importance, and every reasonable care is exercised to prevent interruption of the service. It is the practice of the telephone company to provide distinctive markings on wires used in these services wherever they appear on frames and terminals, and cable splicers are given special instructions when they work on cables carrying such wires.

In addition to the various methods of pilot wire protection, as pointed out by the authors, there are cases in which heat coils and carbon block protections that are potential sources of interruption in central offices, especially in intermediate central offices, can be removed without hazarding the telephone plant. On the power supervisory circuits in Chattanooga, Tennessee, the heat coils are omitted at 2 intermediate central offices.

The neutralizing transformer appears to be a forward step toward improving continuity, which is so desirable a feature in furnishing facilities for pilot wire circuits and telemetering circuits to power generating or substations that are subjected to high rises of ground potential.

Attention is directed to figure 6 of the paper, in which is shown an arrangement of a neutralizing transformer in the battery feed wires instead of at the cable entrance. Although this arrangement permits several pilot wires to be operated through a single transformer, it also imposes the necessity of high insulation on the cable entrance and the relays and other equipment in the pilot wire circuits.

Figure 1 of the paper shows the recommended arrangement, with the neutralizing transformer located at the cable entrance. With this arrangement all interior circuit equipment always should be at station potential and thus safe at all times for handling by attendants. The requirements for high insulation in the wiring and equipment of the circuits then is removed, and the danger of outside damage by insulation breakdown at any of numerous points in the equipment assembly is obviated.

The neutralizing transformer in the cable entrance also should be more effective in reducing operation of carbon block protectors than when it is in the battery feed wires.

It is the desire of the telephone company to co-operate with the power company to produce the service required. The telephone company can furnish reliable facilities if these facilities are used in a manner consistent with their nature. That pilot wire relay protection can be provided efficiently through the medium of telephone wires seems fully established by the experience back of this paper.

W. R. Brownlee and **E. E. George:** The importance of supervision of pilot wire equipment could well have been emphasized more strongly. The practice outlined by C. M. Longfield of making a manual check of the pilot wire equipment on every operating shift has been considered sufficient by the proponents of carrier current pilot wire, since continuous supervision of the latter is difficult to attain.

In the case of ungrounded d-c pilot wire (and this probably applies to an equal extent in the case of carrier current pilot wire) a single equipment defect ordinarily will cause no incorrect operations if it is discovered and corrected before a second defect occurs. Frequently these original defects are of such a nature that they would be indicated by the supervisory equipment only at such times as the circuit is being exposed to some disturbance such as induction, rise of ground potential, or other transient influences. It is almost impossible to locate such transient defects unless continuous supervision is provided. J. H. Neher suggests that supervisory current of approximately 1 milliampere should be satisfactory without using rectifiers and battery reversal. On the basis of a battery supply of 125 volts direct current and a resistance of the tripping circuit (consisting of 2 tripping relays and the pilot wire channel) of 2,500 ohms, it is likely that a difference of 10 per cent that might not be detected readily with extremely delicate voltage re-

lays would be caused by an accidental circuit resistance at any of the various junction points of some 12,500 ohms. Under such a condition the tripping current would be limited to $^1/_6$ of its normal value, which probably would be insufficient to operate the tripping relays. From figure 6 of the paper it may be seen that the supervisory current of the rectifier system is approximately equal to the tripping current.

B. M. Jones and L. C. Bell have called attention to certain difficulties that sometimes are experienced with directional ground relays. Although this condition has not been analyzed in detail, experience has indicated that directional ground relays using residual voltage and residual line current are decidedly more susceptible to such incorrect operations than are those relays using transformer bank neutral current instead of residual voltage for the polarizing elements. For this, and other reasons, the use of voltage polarized directional ground relays practically has been abandoned.

C. H. Frier has mentioned difficulties due to induction in open wire pilot circuits. Short circuit tests recently were made by the company with which the writers are connected for the investigation of the use of neutralizing transformers with special connections for protection against this hazard.

The writers agree with O. J. Huie that the pilot wire equipment shown in figure 6 of the paper could best be protected by a 3 circuit neutralizing transformer at the entrance of the cable pairs instead of with a single neutralizing transformer on the battery. At the time this substation was being constructed sufficient studies and short circuit tests on neutralizing transformers had not been made to be certain of their effectiveness for this application; accordingly, relays and switchboard equipment having high insulation were provided, together with an insulated rack of dry cells for battery supply. Later, the neutralizing transformer was installed in order to permit the use of the regular station control storage battery, which could not readily be insulated.

O. C. Traver points to a responsibility divided between the power company and telephone company and questions the general utility of the writers' local solution of equipment and maintenance difficulties on Bell System circuits. The Bell System has a thoroughly organized method of distributing developmental standards to all of the associated Bell Companies and it is believed, therefore, that the solution to the pilot wire channel difficulties that have been reached in Tennessee soon will be available generally.

It is interesting to observe the speed with which carrier current advocates rise to argue in favor of carrier current protection instead of metallic pilot wire. The present emphasis on price by manufacturers indicates they realize that the high cost of carrier in the past has prevented its general use. During the last few years the company with which the writers are connected has done very little transmission line construction, and they naturally turned to metallic pilot wire for protecting the relatively short distribution tie lines recently constructed. In common with most utility engineers the writers find that they cannot guide their development work along lines that they or the electrical manufacturers might consider most desirable, but are forced to confine it to a solution of immediate pressing local problems. Certainly the development of metallic pilot wire protection has not hindered the manufacturers in improving and cheapening carrier current relay protection. The writers thank O. C. Traver for his comments on vacuum contact relays and for correcting our statement on tapped tie lines.

It is encouraging that relay engineers are not all in complete agreement on any one outstanding type of protection. Perhaps in the past too many have tried to find a universal scheme, because it is always easier to protect a system if uniformity in methods prevails. Various forms of pilot wire and other differential schemes make each section of the system independent, so that the relay engineer may apply many types of protection to suit local conditions. Probably this results in better overall performance than the use of a single uniform type.

The fundamental purposes of metallic pilot wire and carrier current pilot wire are practically identical, and $^9/_{10}$ of the arguments of the paper in favor of metallic pilot wire could be used equally well in justifying carrier current equipment, since the cost of the latter is to be reduced and the original schemes have been greatly simplified. It is believed that it should have a large and important field and the writers expect to consider it for any new transmission lines.

The writers are grateful for the amount of interest that has been indicated, and for the encouraging comments received.

Lightning Protection of Distribution Transformers

Discussion and author's closure of a paper by J. M. Flanigen published in the December 1935 issue, pages 1400–05, and presented for oral discussion at the protective devices session of the winter convention, New York, N. Y., January 30, 1936.

K. B. McEachron (General Electric Company, Pittsfield, Mass.): J. M. Flanigen's paper is of particular interest because of the large number of storms occurring in Georgia. Based on a 20 year average, as determined by the U.S. Weather Bureau, Georgia has 60 storm days per year compared with 40 for Chicago or Philadelphia, and 20 for Boston. Thus, with an increase of $^1/_2$ in the number of storm days, one might expect a somewhat similar relation with respect to the number of failures of transformers and lightning arresters, other factors being equal, which of course cannot be true. Comparing Chicago or Detroit with Atlanta, the shielding is entirely different, Atlanta representing more nearly rural exposure than many of our cities of similar size. It is of interest to compare some of the results for Chicago given by Halperin and Grosser ("Lightning Investigations on a Distribution System," Elec. Engg., v. 56, Jan. 1936, p. 62–69) with those found by Flanigen. The average rate of transformer burnouts, with the arrester not interconnected, in Chicago since 1920 is slightly under 0.4 per cent per year. For Atlanta, the average failure rate for the 2,300 volt system, as shown in table II of the paper, for the period 1932–1935, was 1.47 per cent. This does not seem to be greatly different from Chicago data, if the Chicago record is increased by $^1/_2$ for increase in number of storm days, and approximately doubled for the difference in shielding. Such a correction does not appear to be excessive, in view of the data given by Halperin and Grosser, showing an increase of 57 per cent between urban and suburban lines, and the results shown by a previous paper ("Discharge Currents in Distribution Arresters," K. B. McEachron and W. A. McMorris, Elec. Engg., v. 55, Dec. 1935, p. 1395–99) in which the rural frequency of arrester discharge for a given current was found to be about $3^1/_4$ times that of the urban arrester. Applying such a correction factor to the Chicago failure rate would make the expected rate of failure in Georgia 1.2 per cent. Actually, in 1932, the only year for which a record is available, without some interconnection, the rate was 1.38 per cent. For the entire system the rate was 1.47 per cent.

It is probable because of the increased number of surges in Georgia, and also because of the higher ground resistance, that transformers of the same age have had perhaps 3 times as many surges applied, which would tend to increase the number of transformer failures even after interconnection.

Compared with Chicago, there appears to be a greater year-to-year variation in the number of transformer failures, indicating perhaps a greater variation in storms from year to year.

For systems having data on transformer failures, as reported by L. G. Smith ("Distribution Transformer Lightning Protection Practice," Elec. Engg., v. 55, Jan. 1936, p. 47–53), a failure rate of 0.823 per cent was obtained for 161,810 distribution transformers for the year 1934. This is for the standard arrester connection and includes all classes, both rural and urban.

With standard connection, the proportion of blown fuses, according to Smith's data, roughtly is 10.2 times the number of transformer failures, but with interconnection this ratio is approximately 8.4, representing a total number of transformer years of about 170,000. This is to be compared with a ratio of 15, representing data for 71,937 transformer years taken from Flanigen's table I. This is comparable with the average taken from Smith's results when it is remembered that the Georgia data represent fuse blowing from all causes, but Smith's results are based on fuses blown by lightning only. The Georgia data include both standard and interconnection, and it is not possible to separate them from the data given in the paper.

Unfortunately, similar comparisons with reference to the 6,900 volt and 11,500 volt transformer failures cannot be made because of lack of data. The rate of failure on the entire Georgia system for these 2 ratings is 2.4 and 5.9 times the failure rate for 2,300 volt transformers. In general, the lightning arrester used will have its protection potential increased in proportion to the system rating, but the transformer strength will not increase in direct proportion to its rating. This means a relatively small factor of safety as the voltage rating increases which undoubtedly accounts for part of the increase in the failure rate. With interconnection and modern arresters and transformers, the factor of safety should be ample to hold the lightning failure rate to only

slightly more than for the 2,300 volt transformer under similar conditions of exposure.

Lightning arrester failures result from inability to discharge lightning currents, or inability to stop power current. Often arrester failures result from the operation of circuits in such a manner that 60 cycle potentials in excess of the arrester's rating are applied at times. If a transient large enough to spark the arrester's gap occurs at the same time, a failure is likely to occur. There is little general evidence to show that modern distribution arresters are damaged as a result of the lightning discharge. Laboratory tests have demonstrated that an arrester such as the pellet is capable of passing several discharges of more than 70,000 amperes for short periods without becoming inoperative or submitting to an impairment of its characteristics.

Using the arrester failures given in table I of the paper, the annual rate for the entire system, including all ratings, is about 2.5 per cent, assuming that the last 3 months of 1935 would have an inappreciable number of failures. L. G. Smith gives an average rate of arrester failure of 1.06 per cent with interconnected arresters, and 1.65 per cent with standard connection, for 72,599 and 80,872 transformers, respectively. Excluding the year 1934, the arrester failures in Georgia vary from 1.08 per cent to 1.51 per cent, which are the same order of magnitude as reported by Smith. A list of the arrester failures by arrester rating would be interesting, if such data are available.

Taking the greatly increased activity of lightning into account, the writer believes that the operation of the Georgia Power Company distribution system compares favorably with the rest of the country. Much improvement can be made; interconnecting with short leads and grounding the tanks of the transformers of high ratings will help the transformer failure record, and greater care in maintaining the system voltage across arresters to values within their rating at the time of discharge should help to reduce the rate of failure of arresters. Further improvement by the manufacturers of both transformers and arresters, and additional knowledge of the factors involved, should make for a still better record, not only in Georgia, but throughout the country. The use of the secondary neutral grid, where feasible, also should assist in the general problem of lightning protection of distribution transformers.

L. G. Smith (Consolidated Gas, Electric Light, and Power Company of Baltimore, Md.): The author has brought out the point that the number of lightning days is about the only basis of comparing the severity of lightning seasons from one year to another. Although this apparently is the only means of making comparisons, it should be realized that severity of individual storms will have a material effect. For instance, on the system of the company with which the writer is connected, there were 39 lightning days and 10.9 per cent rate of primary fuses blown in 1934, whereas in 1935 there were 38 lightning days and the rate of primary fuses blown was only 8.7 per cent.

The author infers that interconnection has not accomplished the desired results on this system; however, the data submitted by his company for 1934 shows that on a 3 phase, 4 wire system, primary fuses blown with interconnection were only 22 per cent of the rate for fuses blown with standard connection and the rate for transformer winding failures with interconnection was only 26 per cent of the corresponding rate for the standard connection. On the delta system the results were not quite as good, but an improvement was noted, for the rate of primary fuses blown and transformer winding failures was about 64 per cent of the corresponding rate for the standard connection. The 1935 data that are reported in the paper show somewhat similar results; therefore, troubles may still be experienced with interconnection, but their rate should be reduced considerably.

In reference to the author's statement regarding lightning arrester failures, the combined data obtained from 38 operating companies indicate that with the standard connection there is trend toward reduced failures with increase in ground resistance, which is in accordance with theoretical conceptions. With the interconnection, however, a reverse trend seems apparent, which is similar to the trend reported by the author. Another point to be considered in reference to lightning arrester failures is that much depends upon the type of arrester. For example, in a 5 year period, the writer knows of the failure of more arresters of one type than of a second type, whereas probably not more than twice as many arresters of the second type were in use.

H. N. Ekvall (Philadelphia Electric Co. Philadelphia, Pa.): This paper presents some very interesting analyses of a number of factors associated with lightning trouble investigations. Of particular interest are the data indicating the performance of the interconnection on distribution transformers. They show a ratio of about 2 to 1 in favor of the interconnection. This is based on a comparison of the rate of trouble on all protected transformers having the interconnection with the rate of trouble on all transformers without the interconnection. This comparison apparently is based on the combined experience on 3 systems of different voltages—2,300, 6,900, and 11,500.

It is questionable whether a fair determination of the benefits of the interconnection can be obtained from these combined data particularly when the rates of trouble on the 3 systems differ appreciably. Even when dealing with a single system the results may be misleading from an over-all performance standpoint because of the differences in the rates of trouble on various sizes of transformers.

To overcome this difficulty, a "weighted" method for determining the over-all performance of the interconnection is suggested for consideration. This is based on an analysis of troubles by size groups, selecting for each group transformers that have about the same rate of trouble. For each size group, comparisons are made of the number of actual troubles on protected transformers to the number of probable troubles that would have occurred on these transformers had protection been omitted. The probable troubles are determined by multiplying the number of protected transformers in a given size group by the rate of trouble for other transformers in that group. For all sizes the total actual troubles are compared to the total probable troubles. The performance ratio obtained in this way for all sizes may differ considerably, depending on the system, from that determined in the conventional manner using rates of trouble without due regard to size.

Table I—Conventional Method of Determining Effectiveness of Interconnection

Size Groups Kva	Number of Transformers		Cases of Trouble		Cases per 100 Transformers		
	Protected	Unprotected	Protected	Unprotected	Protected	Unprotected	Ratio
					A	B	B/A
1/2– 5	335	222	12	19	3.58	8.56	2.4
7 1/2– 15	677	829	17	47	2.51	5.67	2.3
20 –200	1,327	4,448	8	84	0.60	1.89	3.1
All sizes	2,339	5,499	37	150	1.58	2.73	1.7

The conventional and weighted methods are illustrated in tables I and II, respectively, of this discussion, based on 1935 fuse and transformer lightning trouble data for the 2,300 volt, 2 phase system in Philadelphia. Although the ratios obtained by both methods are the same for individual size groups, they differ for the over-all or "all sizes" group. The conventional method shows a ratio of 1.7 as compared to 2.5 by the weighted method. The 1.7 ratio is lower than that for any of the individual size groups, whereas the 2.5 ratio, by the weighted method, falls within the range of values for individual size groups, and therefore is believed to be more nearly representative of the over-all effectiveness of the interconnection.

This weighted method was referred to briefly in a previous paper "Distribution System Lighting Studies" (A.I.E.E. Trans., v. 51, March 1932, p. 265–71). It is mentioned again primarily for the benefit of those who may care to use it in comparison with their own methods for evaluating the effectiveness of the interconnection.

Herman Halperin (Commonwealth Edison Co., Chicago, Ill.): A study of J. M. Flanigen's data shows that for the entire Georgia Power Company the ratio of fuse blowings to transformer failures caused by lightning averages about 16—an unusually high figure. The ratio for the system of the company with which the writer is connected has been approximately $2^1/_2$. The writer wonders whether the high ratio for the Georgia system results partly from fusing for overload, instead of requiring heavier fuses designed to blow only in case of short circuit.

The writer is glad to be able to support with quantitative data Flanigen's conjec-

tures regarding substantial surge voltage drops in leads, and regarding the floating of the ungrounded transformer tank. In the writer's opinion, the remedies Flanigen proposes, that is, shortening the interconnection tie and grounding the transformer tank to the secondary neutral, will do much toward reducing lightning troubles.

J. G. Cree (Metropolitan Edison Company, Easton, Pa.): The records of the company with which the writer is associated indicate an apparently increased vulnerability of distribution transformers set on the ends of rural line spurs, where increased voltages might be expected from the reflection of surges. Nearly 1/2 of the lightning trouble experienced from blown fuses and transformer failures occurs at such locations. Has this observation been made by others, and should increased attention be given to the protection of transformers so located?

J. M. Flanigen: The discussion of all of these papers has brought out some very interesting points, especially that it is almost impossible to forecast the detrimental effects of lightning.

H. N. Ekvall has cited a very interesting method of comparing the relative merits of the different schemes of protection. In the case of the Georgia Power Company, the relative improvement is raised from 1.83 to 2.04. This suggestion is appreciated, and probably it will be used in future comparisons.

J. G. Cree's comment, that more trouble occurs at the ends of lines, is true for lines originating within the shielded area of a town and extending into open country. The writer has found, however, that in case of a line extending between 2 towns, beginning and terminating within the shielded areas of the towns, then most of the troubles occur along the line rather than at the ends.

L. G. Smith's comment regarding the comparison of the failure rates of arresters is substantiated by the writer's experience, in losing a greater proportion of arresters of one manufacturer than of all the others.

The ratio of fuses blown to transformer failures has been used for a number of years to develop a satisfactory fuse table. This ratio has been the one criterion of the efficacy of fusing practice. The writer has used 3 or 4 tables in the past 10 years, going from overload protection to short-circuit protection, and he is now using a table that averages about 250 per cent rating at 20 seconds. However, the per cent rating was not used as a basis for making up the table. Other items, such as motor starting currents and thermal ability of the transformer, formed the basis of the development of the practice.

Table II—Weighted Method of Determining Effectiveness of Interconnection

Size Groups Kva	Number of Transformers [II]Protected	Cases of Trouble: Actual With Protection	Cases of Trouble: Probable Without Protection	Ratio
		A	*B*	*B/A*
1/2– 5	335	12	28.7[I]	2.4
7 1/2– 15	677	17	38.4[I]	2.3
20 –200	1,327	8	25.1[I]	3.1
All sizes	2,339	37	92.2	2.5

[I] Determined by multiplying number of protected transformers by rate of trouble on unprotected transformers. For example, for the 1/2–5 kva group, 335 $\times$ 8.56 = 28.7 troubles that probably would have occurred had protection not been applied.

[II] Arrester ground lead solidly interconnected with secondary neutral on protected transformers.

Distribution Transformer Lightning Protection Practices

Discussion of a paper by L. G. Smith published in the January 1936 issue, pages 47–53, and presented for oral discussion at the protective devices session of the winter convention, New York, N. Y., January 30, 1936.

E. E. George (Tennessee Electric Power Co., Chattanooga): The author's discussion of the advantages of the common neutral system of distribution, and other papers on distribution design and relay modernization suggest brief mention of the protective difficulties encountered with certain common neutral systems. These difficulties are serious on rural 6,900 volt or 7,600 volt systems on which the loads are light and the lines are very long. This type of construction recently has become prevalent in the Southeast and Southwest. Its use has been promoted largely by equipment manufacturers, and by the apparent necessity of certain utilities to compete with the federal government. Many extreme features of common neutral construction have been used in the rural lines that government agencies have financed, designed, and constructed for municipalities and co-operative organizations in the Southeast.

Common neutral construction has been advocated by many distribution engineers because it seems undoubtedly much cheaper in first cost than anything else. However, much of the saving is lost by the additional station expense made necessary on many systems in order to eliminate interference with the existing relay systems and with existing totalizing station metering.

Some distribution engineers infer that selectivity can be obtained whenever the fault current is greater than the load current, but relay engineers know that the fault current must be several times the load current if selectivity is to be obtained by relays that must carry the load current. Distribution engineers have placed too much reliance on fuse characteristics. Manufacturing variations, combined with the practical difficulty of supervision in replacement make a distribution fuse almost worthless as a selective protective device.

The writer does not know how to protect long lightly-loaded single-phase 6,900-volt common neutral rural lines, and he does not know anybody who does know how. A lot of claims have been made, but when they are investigated it is generally found that the engineer who has the responsibility for protection has no satisfactory solution, or has worked out some apparent remedy that has not survived a complete lightning season.

The paper makes it clear that the advantages of interconnection are available without common neutral construction. The chief argument for common neutral construction, namely the saving in secondary conductor, does not exist where farm line transformers are used, since there is one transformer per customer. The supposed advantage of better grounding conditions because all grounds are connected in multiple, is of doubtful application to rural service where customers are so far apart that lightning attenuation must be considered.

T. H. Haines and **W. B. Elmer** (Edison Electric Illuminating Co. of Boston, Mass.): One of the author's chief conclusions, stressed throughout the paper, is that low ground resistance is one of the chief factors in improving lightning protection. It is easy to understand why decreased ground resistance improves protection with the standard connection, but with the interconnection it is more difficult to understand.

As the theory in this case is understood, ground resistance should play practically no part in improving arrester protection. The shunt connection should serve to limit the transient voltages between the primary and secondary windings, and if the case and core are not grounded they should assume a potential of some intermediate value between the 2 windings. The whole transformer, if this theory is correct, should be relieved of excessive differences of potential between any of its parts.

Figures 6, 7, and 8 of the paper seem to indicate a tendency toward low trouble rates with low ground resistance. The question of why low ground resistance assists the interconnection in decreasing trouble rate now arises.

The following appears to be a logical explanation: If the poles are generally good insulators, the theory that the transformer cores and coils will assume potentials intermediate between the 2 coil potentials may be valid. This theory apparently was demonstrated by McEachron and Saxon (see "Lightning Protection for Distribution Transformers," A.I.E.E. TRANS., v. 51, Mar. 1932, p. 239–44), who concluded that "nothing is to be gained with the interconnection by connecting the transformer tank to the secondary neutral, since with the tank floating, the potentials developed to tank are much less than the strength of insulation involved, and the hazard to linesmen is decreased." However, if the poles are poor insulators, and particularly during rainstorms when their insulating value is reduced, and on poles with grounded communication messengers attached near the trans-

former, the transformer cases may remain substantially at ground potential, but the primary and secondary coils rise in potential according to the quality of the arrester ground system. If the case and coils develop great potential differences from this cause, flashovers could be expected, and the trouble rate should vary with ground resistance, as shown in the paper.

The effect thus described probably could be corrected by connecting the case to the arrester ground lead, either directly or through a gap. The writers experimented with such case gaps on a limited number of locations with so-called standard connections before the use of interconnection, with negative results. Since interconnection has been established the record seems to have been slightly better at these locations than at comparable ones without the gaps. The number of locations was so small that sufficient data has not been obtained to draw definite conclusions. It is possible, however, that by this type of connection the value of ground resistance would be rendered immaterial as far as transformer trouble is concerned.

In figure 2 of the paper, gap *B* is shown in the position under discussion. It would be of interest to see the results for interconnection as shown in table II subdivided further, to include the following headings: "all interconnections"; "solid interconnections"; "interconnections with gap *A*"; "interconnections with gap *B*."

The foregoing theory is corroborated by the third conclusion in the paper by Halperin and Grosser ("Lightning Investigations on a Distribution System," ELEC. ENGG., v. 55, Jan. 1936, p. 63–70) as follows: "measurements of lightning surges indicate that for most surges the potential of the ungrounded transformer tank remains near ground potential. This permits high surge voltage to appear across the transformer bushings in spite of the protection afforded by the arrester, accounting for many of the lightning troubles that still occur with interconnection."

H. V. Putman (Westinghouse Elec. and Mfg. Co., Sharon, Pa.): The transmission and distribution committee has presented an excellent report, and deserves much credit for its summary of present distribution transformer lightning protective practices. Collecting data of this kind is a difficult task, but such information can be of great value. However, the statistics presented for surge protected transformers lead to the surprising conclusion that those transformers produce more fuse outages than the interconnection, and less effective in protecting the windings. Since this conclusion is contrary to all experience and to all of the data that the writer has been able to collect, the report has been studied closely to find the reason.

The writer has found that practically all winding failures were reported by one company, number 15, and that this company experienced 14.3 times as many winding failures as the average for all the other 23 companies reporting. It was found also that the majority of the fuse outages were reported by one company, number 7, and that this company experienced 6.7 times as many fuse outages as the average for the other 23 companies reporting. Obviously, when one company experiences 14 times as many winding failures as all others, and another 7 times as many fuse outages as all others, there must be some explanation. The writer has that explanation because he has kept very careful records of the field experience of surge protected transformers.

The writer has observed also what appears to be a 2 to 1 error in the percentage of deionizing gap failures, about which some comment may be proper.

Consider the record of winding failures: out of the 24 companies reporting on surge protected transformers, 22 did not report a single winding failure; company number 7 reported 1 winding failure in 551 transformers; company number 15 reported 6 in 591 transformers. The writer's own records for company number 15 show 5 winding failures up to August 20th, 1935. Another may have occurred after that date, of which there is no report.

All 5 units were returned to the factory for examination and dielectric tests. Of these units, 1 was found to be in good condition, 2 had very obvious mechanical defects in the windings, and 2 showed definite signs of water having been in the transformers. It was learned later that the deionizing gaps in these transformers blew up during a rain storm, blew the covers off, and let water get inside the cases. Tests in the customer's laboratory were made without drying, and it was undoubtedly these tests instead of lightning that broke down the windings; consequently, it appears that none of the 5 reported winding failures can be considered to be a legitimate failure due to lightning. There may be considered 2 indirect failures due to the gaps blowing up, but since the earliest design of the gap this trouble has not been experienced.

In connection with the failure reported by company number 7, the deionizing gaps showed markings on the faces of the electrodes indicating approximately 65,000 surge amperes for 50 microseconds, which was sufficient to shatter the gaps. The winding easily could have failed as a result of a second surge subsequent to the destruction of the gaps, and that probably is what happened. It is questionable, therefore, that this failure can be counted against 3 point protection be cause the failure probably took place with the winding entirely unprotected.

Thus, when this record of winding failures is analyzed and separated from the deionizing gap failures, it is found that the record of 3 point protection with deionizing gaps is practically perfect. Omitting the data on company number 15, the percentage of winding failures in 1,400 transformers is only 0.07 per cent, and this is only $1/_5$ of the winding failures reported for the interconnection.

Consider now the record of fuse outages: company number 7, having 27.5 per cent of all the transformers on which data are reported, experienced 9.78 per cent of the fuse outages, which, as indicated before, is about 7 times that for the average of all other companies.

When this trouble was called to the writer's attention it was found that the company was using an aluminum wire fuse link, which they considered to be the equivalent of the 10 ampere standard link that is recommended. Actually it was found in the laboratory that the aluminum wire link had much less current carrying capacity. The $1/_2$ cycle of power follow that sometimes occurs in the deionizing gap, coupled with only a very small surge current, was sufficient to open the link. It was demonstrated that the substitution of a standard 10 ampere link for the aluminum wire practically eliminated that trouble.

The fuse outage record of company number 7 is, therefore, due to the aluminum wire links and is not inherent in the surge protected transformer. The data on company number 7 should be eliminated if a correct picture is desired of fuse outages that operating companies are experiencing generally. The following data is the average for 23 companies:

	Number of Surge Protected Transformers	Per Cent of Fuse Outages	Number of Fuse Outages
Total	1,994	3.77	75
Company number 7	551	9.78	54
Total excluding company number 7	1,443	1.46	21

This shows a fuse outage record, based on 1,443 units, of 1.46 per cent. Before comparing this with the interconnection experience, some consideration should be made of the different exposure to lightning, since practically all of the 107,000 interconnected transformers are in cities with water pipe grounds where the national electric code permitted such connections in 1934.

The locations of surge protected transformers as given in the report have been tabulated, and omitting 181 transformers on which 4 companies did not report the location, 95 per cent of all surge protected transformers were found to be in rural or suburban locations. Those companies having only a few surge proof transformers have at the suggestion of the company with which the writer is connected, placed them in their worst locations from the standpoint of lightning troubles.

This makes a big difference in the fuse outage record, not only because of the greater exposure to lightning, but also becaue rural transformers are generally, smaller in size and have smaller fuse links.

In order to make a comparison of fuse outages with the interconnection on the same basis, the data from the report of the 4 companies using the interconnection exclusively in rural locations has been summarized as follows:

Company	Number of Units	Per Cent of Fuse Outages	Number of Fuse Outages
7	28	0	0
14 (solid)	97	10.3	10
14 (gap)	98	9.2	9
19	72	7.2	5
35	193	30.0	58
Total	488	16.8	82
Total excluding companies 7 and 35	267	9.0	24

The summary covers 488 interconnected transformers in rural locations and shows 16.8 per cent fuse outages. The record of

company number 30 was outstandingly bad, with 30 per cent fuse outages in 193 transformers, and the record of company number 7 is outstandingly good with no outages in 28 units. If both are omitted from the summary it still shows 9 per cent fuse outages, which is probably closer to the results that would be obtained with the interconnection in rural locations if data were available on a larger number.

At this point a comparison can be made between fuse outage experience with surge protected transformers and interconnections under comparable conditions of size and lightning exposure. The data available indicate that the ratio is 1.46 per cent for the surge protected transformers and 9 per cent for the interconnection. This comparison agrees closely with the writer's experience and data. It indicates that the surge protected transformer will reduce fuse outages in rural locations to about $^1/_5$ that experienced by the interconnection.

The reason lies in the fundamental difference between 3 point protection and interconnection. The interconnection assumes that the tank will float at a potential somewhere between that of the high voltage and low voltage windings. Herman Halperin has demonstrated that in practice the tank potential often remains comparatively near ground potential, but that of the windings and leads rises to the potential of the incoming surge. This causes flashover from leads to cover or over-stud type bushings with resultant fuse outages. Some effort has been made to point out this fundamental difference between the interconnection and 3 point protection and it is believed now that the merits of 3 point protection is about to be appreciated where the tank is tied into the circuit and its potential is definitely established in relation to that of the windings.

In conclusion, the writer wishes to comment on the record of deionizing gap mortality. Practically all of the deionizing gap failures have occurred with the very earliest design, which had an ultimate surge current capacity of 10,000 amperes. By changes in the construction of the series resistor, the ultimate surge current capacity was increased to 40,000 or 50,000 surge amperes. Since then, refinements have been made to increase the surge current capacity of the present gaps to approximately 100,000 amperes. For nearly a year commercial surge current tests have been made on each deionizing gap going into a surge protected transformer of any type. These tests are carried out at from 60,000 to 65,000 surge amperes with a duration of 50 microseconds. Since these tests were started early in 1936, some 53,000 gaps have been produced and tested, and although not all of them are in service, there has not been a single failure of any of these gaps in the field. It may be said, therefore, that the problem of gap mortality has been solved.

The writer has not been able to check the number of gap failures given in the report. It appears that a mistake of about 2 to 1 has been made. For example, take the case of company number 15: according to the company's own report to the factory, 17 gaps had failed up to August 20th, 1935, and all of them occurred with the earliest type. There may have been another after that date, of which there is no record. That would make a total of 18. It is believed that the 18 gap failures have been divided by 591 transformers to obtain the percentage of 3.05 per cent for gap mortality. Actually, however, the total number of gaps is 1,182, and the percentage failure is 1.52 per cent instead of 3.05 per cent in the case of company number 15.

There appears to be something wrong also with the data presented for company number 9, which indicates 16.16 per cent, or 32 gap failures in 99 transformers. How could 32 gap failures take place in 99 transformers and, at the same time, produce only 1 fuse outage? Certainly there would have been a fuse outage for each gap failure. Any case of 32 gap failures in 99 transformers in a single year certainly would have come to the writer's attention. It appears that the data presented on deionizing gap mortality have been incorrectly interpreted, or have been incorrectly translated into the percentage figure, and that the actual result is at most not more than $^1/_2$ that indicated in the final summary. The figure of 2.25 per cent gap mortality probably should be 1.13 per cent. In the future, with the new gaps this figure should be just about zero, because a pair of the new gaps will withstand any ordinary direct stroke of lightning without damage.

L. R. Ludwig and **A. M. Opsahl** (Westinghouse Elec. and Mfg. Co., East Pittsburgh, Pa.): The tabulations and data presented by L. G. Smith undoubtedly will be of value because of the completeness of the data and the large number of operating companies that have reported. Some care is necessary, of course, in studying statistical information of that kind, because of the large amount of generalization necessary to compile the facts in usable form. For example, Smith's tables show that the percentage of fuses blown with the gapped interconnection is less than with the solid interconnection. This result may not necessarily indicate a weakness of the gapped interconnection because, as Smith has stated, the location of the primary fuses was not known, and because the gapped interconnections are mostly in rural territory. As another example, the length of the interconnection lead may vary considerably from one company to another, and this also may modify the results; consequently, comparisons must be made with care.

Smith has concluded that the arrester loss actually is no higher with interconnection than without it. Certainly the duty on the arresters will be higher with the interconnection but the fact that newer and higher capacity arresters probably have been installed when interconnections were made is likely to explain the equally good arrester performance with interconnection. In some of the other papers, Herman Halperin's for example, the statement is made that the arrester failure rate is higher with interconnection, which seems to substantiate the belief that better arresters are required with interconnection.

The entire group of papers suggests that terms used in describing the protective circuit connections should be better defined and understood; particularly the terms "interconnection" and "3 point protection" are variously used by different authors. The type of interconnection using a gap to the transformer tank shown in figure 2 of the paper, is referred to by many as "3 point protection." Smith's diagram of 3 point protection is much more elaborate and utilizes more gaps than the usual suggested form of this type of connection. In the author's tables it might be more desirable to combine the results for 3 point protection with the results for interconnection, and simply differentiate between gapped interconnection and solid interconnection, placing the 3 point protection in the gapped interconnection group.

Herman Halperin (Commonwealth Edison Co., Chicago, Ill.): The author has given some recognition to the technical weakness of drawing conclusions from straight averaging of numerous data from different systems. It might be pointed out, however, that different results would be obtained from his paper if only those companies having good comparative data for normal arrester protection and for interconnection were considered. The ordinary method of averaging shows that with the solid interconnection, arrester and meter failures were only 63 per cent and 11 per cent, respectively, of those with normal arrester protection. Weighted averaging of the data from only the suitable companies, that is, numbers 2, 10, 13, 15, 19, 23, and 30 for arrester failures, and numbers 2, 4, and 19 for meter failures, indicates that the ratio was 63 per cent for arrester failures, instead of 95 per cent, and instead of 11 per cent for meter failures it was 225 per cent. In fact, 4 of the 7 companies mentioned reported an increase in arrester failures when the interconnection was used; hence, there appears to be insufficient justification for Smith's fourth conclusion, even with its carefully restricted qualifications, that the use of interconnection results in a decrease in arrester failures.

It is difficult also to understand from theory or present available information how the magnitude of ground resistance has any material effect on rate of troubles due to lightning when interconnection is used.

Smith states that one company found $^1/_8$ of the transformer coil failures due to lightning to involve both primary and secondary windings. For Chicago the percentage involving this type of failure has been more than twice as large.

W. A. McMorris (General Electric Co., Pittsfield, Mass.): The results of the survey reported in the paper are particularly significant because of the large mass of data included. The performance of each of several methods of lightning protection is summarized in table I of this discussion, and is compared to the conventional or standard lightning arrester connection. If these results are compared with those for the method in which the lightning arrester grounds are interconnected with the secondary neutrals, which in the past few years has rapidly been replacing the standard connection, the results are as shown in table II of this discussion.

Among other factors that influence the interpretation of these results are the number of installations involved in each case, the difference in average ground resistance, and the fact, as pointed out by the author, that the surgeproof transformers were practically

Table I—Lightning Damage to Distribution Transformers Protected by Various Schemes

Method of Protection	Relative Cost of Repairing Damage
All interconnections	1.00
Surgeproof transformers	1.32
3 point protection	2.24
Standard connection	2.48

new. For modern protective methods such as the use of interconnection, surgeproof transformers, and 3 point protection, in which the protective devices are in direct shunt relation to the insulation to be protected, theoretical considerations indicate that protection to the transformer is not affected materially by the arrester ground resistance. The experience of individual companies does not in all cases agree with the results of the survey as a whole, but no doubt these discrepancies will disappear when more data are accumulated and the differences in operating conditions are taken into account.

In table I of this discussion a comparison is made of the cost of repairing the lightning damage of each of the methods of protection. In arriving at these values, the average unit costs for renewing a blown fuse, repairing minor damage, and repairing or replacing a transformer are assumed to be the same as given by Sporn and Gross ("Lightning Arrester Economics," ELEC. ENGG., v. 55, Jan. 1936, pp. 84–93). Each case of arrester or meter damage is evaluated as a case of minor damage. The number of cases involving only blown fuses is taken as the total number of fuse blowings less the sum of cases of minor damage and transformer damage.

In addition to the better performance for interconnection on the basis of cost of repairing damage, there is also the advantage of better continuity of service, which is very difficult to evaluate; moreover, the minimizing of any adverse effects on customer services is important and of real significance in evaluating the merits of over-all protection.

If the number of meter burnouts can be taken as a criterion, then the extensive data obtained indicates that the arrester interconnection method reduces secondary service troubles to less than $^1/_2$ those permitted by the protection method ranking second in table I of this discussion, on the basis of cost considerations only.

L. G. Smith: This investigation of operating data was made to present operating results from a large number of companies with the end in view of averaging the effect of the variables due to isokeraunic level and degree of exposure. It is possible to do this only by collecting data for a large number of installations for a period of several years. In the case of surge proof transformers, data was obtained on a relatively small number of units for one year. Although it was not possible to present various combinations of operating data in the paper, sufficient data is available in table I of the paper for segregating performance of strictly rural systems as compared with urban and suburban systems. Obviously, in a study of this sort, it is not possible to analyze each failure, as Putnam has done for certain failures of surge proof transformers. Just as certain surge proof transformer failures were due to unusual conditions, undoubtedly numerous failures of interconnected transformers or transformers with standard connection failed due to similar unusual conditions. All of the data used in this report were based upon the operating point of view; that is, if a unit fails, service is lost.

Putnam's comments regarding the fuse blowing of the surgeproof transformers of company number 7 are only partly true for company number 7 is not using aluminum fuse wire for fuse links exclusively. A check made shows that this company is using both aluminum wire and standard links in primary fuses, with the probability of the links being in the majority on the surgeproof transformers. Data from the 1935 lightning season for this company indicate 12.4 per cent primary fuses blown on surgeproof transformers and 4.6 per cent primary fuses blown on interconnected transformers. Both types of transformers are installed in rural districts.

The point that Putnam has raised regarding exposure is a very important consideration. As Putnam says, practically all of the surgeproof transformers are installed in rural districts, only a few being installed in urban or suburban districts. In other words, undoubtedly the urban and suburban installations of interconnected transformers should not be used in making the comparison with surgeproof transformers. However, the total data for interconnected transformers are comparable with the data for the standard connection. Putnam has taken companies 7, 14, 19, and 35 as representative of those using interconnection exclusively in rural districts. Taking those companies that have interconnected transformers only in rural districts, companies 7 and 19 show a lower rate of primary fuses blown for interconnected transformers, and company number 14 shows the same rate.

In reference to Putnam's point regarding the use of the number of transformers as a basis for determining the percentage of gap failures, it must be remembered that from an operating point of view the transformer is an operating unit; therefore, it is believed that the use of the number of transformers as a base is correct. It is hoped that the collection of data for the 1935 season and future lightning seasons will result in covering a greater number of units over a sufficient period of time in order to obtain more comparable results.

T. H. Haines, W. B. Elmer, W. A. McMorris, and Herman Halperin have all raised the point that ground resistance should not influence the performance of interconnected transformers so far as lightning troubles are concerned. However, Haines and Elmer have suggested a probable answer. The paper by Halperin and Grosser introduces another explanation. Both of these explanations are based upon the assumption that the tank potential does does not remain at some value between that of the primary and that of the secondary. For this reason, a type of interconnection with the bank either grounded or tied to the interconnection through a gap might reduce lightning troubles. In collecting the data for the 1935 season an attempt is being made to obtain operating data on this type of interconnection as Haines and Elmer have suggested. Without question, the data collected for the 1934 season indicates that ground resistance does affect the performance of interconnected transformers as well as those with the standard connection.

E. E. George has made a very interesting point regarding relaying of distribution feeders using a common primary and secondary neutral. Although the relaying problem may become more prominent at 6,900 volts or on higher voltage feeders, so far as the writer has been able to determine, there has been no trouble experienced in relaying 4 kv feeders, using the common neutral system. Without going into any detailed discussion of advantages and disadvantages of the common neutral system, there are savings in using such a system other than the saving of the secondary conductor. For instance, as soon as the neutral conductor is thoroughly grounded throughout a feeder it becomes no longer necessary to insulate it, and it can be installed on the side of a pole with a simple clamp, eliminating the need for crossarms on single phase lines, as the phase conductor can be installed on a ridge pin.

Table II—Comparison of Effectiveness of Various Schemes for Lightning Protection of Distribution Transformers

	All Interconnections	Surgeproof Transformers	3 Point Protection	Standard Connections
Number of installations	107,112	1,994	154	165,914
Relative number of fuses blown	1.00	1.32	2.48	2.97
Relative number of winding failures	1.00	1.03	1.07	2.41
Relative number of arrester failures	1.00	2.14	5.96	1.56
Relative number of meters burned out	1.00	2.04	0	9.53

Modernization of Power Distribution Systems

Discussion and author's closure of a paper by H. P. Seelye published in the January 1936 issue, pages 75–84, and presented for oral discussion at the modernization of distribution systems session of the winter convention, New York, N. Y., January 30, 1936.

Philip Sporn (American Gas and Electric Co., New York, N. Y.): The writer was extremely gratified by H. P. Seelye's comprehensive and thorough paper.

Many of the subjects covered by Seelye are of vital importance in the distribution problems encountered on the American Gas and Electric system. As many know, perhaps, that system serves about 1,400 communities in 9 states, all east of the Missisippi River. The outstanding thing about these

communities is that they are all rather small; that is, they are either small urban or definitely rural territories, the average population of these 1,400 communities being approximately 2,100. It is interesting that many of the author's conclusions agree very closely with conclusions on sound distribution practice decided for that system. Several specific examples may be of interest. Those mentioned in this discussion are in the same order discussed by Seelye.

The author states he has found that small substations often serve the purpose better than larger substations. In this the writer agrees with him for the same reasons. Even in some of the larger towns of the American Gas and Electric system it has been found to be economical and advisable to maintain many substations of from 1,500 to 3,000 kva capacity. In general, it has been observed that the service limit of a substation with a 2,300 to 4,000 volt Y primary is about one mile. This service limit is, of course, greater for lightly loaded areas than for heavily loaded sections.

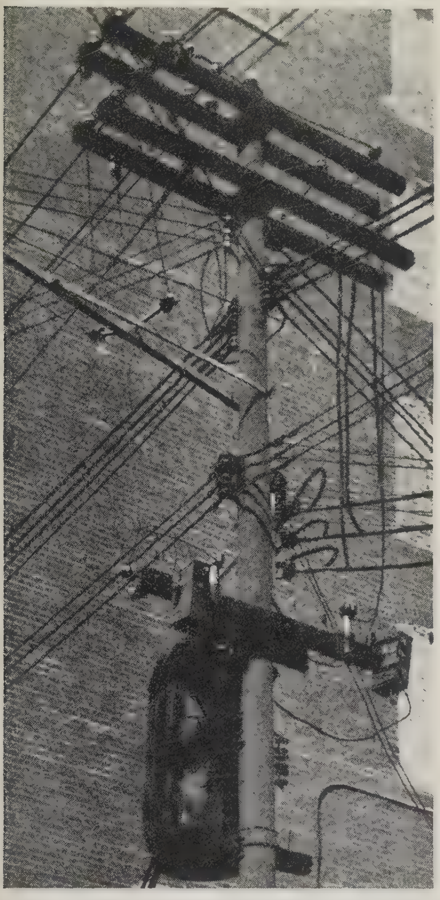


Fig. 1. Portion of a distribution system in a business section, before rebuilding

Studies of the primary network scheme have been made to see whether it could be used to advantage in locations where such possibilities seemed to be indicated definitely. The theoretical advantages of the primary network scheme are many, but it has been found difficult to apply this scheme economically in places where it was desirable to utilize existing substations and primary circuits. In some cases, however, it may be possible to adopt a scheme of developing a system of substations, and primarily distribution lines, which will later adapt itself to the primary network idea.

The writer agrees with Seelye that number 4 and number 2 copper represent the most economical size conductors for use on secondary lines. In fact, this seems to be generally recognized by distribution engineers. Transformer spacings with number 4 and number 2 secondary conductors average from about 600 to 1,000 feet for ordinary residential loads. Larger secondaries often are required of course, for heavier loaded areas, especially in places where transformer locations are at a premium.

On the American Gas and Electric Company properties bare conductors for both primary and secondary circuits are used for farm line construction work. As mentioned by Seelye, class 7 poles, with some class 6 and class 5 poles, have been found adequate. No true economy in abnormally long spans for rural work has been found and spans of about 300 feet are used with some variations, of course, depending upon the size and type of conductor employed. Rural line construction has been simplified and wherever possible the grounded primary system with common primary and secondary neutral conductors is used.

The subject of underground cable for farm line service seems always to have a sort of mysterious attraction for engineers and operators. The writer has attempted to keep in touch with new developments and cables that might have a low enough first cost to be used in rural line extension work, but his studies so far indicate that the costs of using underground cable for rural primary lines would far exceed the costs of overhead rural line primary circuits as they are being built today. This is the conclusion reached by Seelye.

Under present conditions an overhead primary circuit in fairly flat territory using 30 foot poles, 275 foot spans, and number 4 bare copper conductor operating at 6,900 volts to ground, copper return, can be built for perhaps $620 per mile. An underground line using number 6 paper insulated copper sheathed cable, with the copper sheath serving as the neutral conductor, can be built for approximately $1.165 per mile. To obtain the cost of a complete line, the cost of overhead transformers, secondaries and services would have to be added to both estimates. Those additional items would increase the spread between the cost of overhead and underground construction inasmuch as the underground system would require additional cable for the transformer installations, and in addition would require poles for any secondary extensions, which would be already provided in the case of an overhead primary circuit.

In the foregoing underground estimate a paper insulated copper sheathed cable was assumed. It has been noticed that cheaper cables have been made up and are being used on a trial basis in several places. Although actual experience will indicate the true economics of the use of cheaper cables, it is the writer's belief that so far there has been nothing to show that even these cheaper cables will solve the problem satisfactorily, since the maintenance cost is bound to be very high and, in any event, the cable construction proposed would appear to be totally inadequate for 6,900 volt to ground construction.

Most of the rural lines of the company with which the writer is associated through suburban territories and the installed cost of poles and structures is comparatively low. It is possible that underground rural cable might be found economical in cases where structure costs are very high and overhead lines difficult to maintain, but in general it is believed that for the present the applications of cable in rural construction are limited.

Several installations of aerial cables for both primary and secondary distribution circuits have been made. The aerial cable installations were not all made for the same reasons, some being to relieve congestion of wires in and around substations or on pole leads, some to improve appearance of overhead distribution lines in congested areas, and several installations have been made to eliminate tree troubles.

Figures 1 and 2 of this discussion illustrate a condition in which a primary circuit was placed in aerial cable in order to relieve congestion and improve appearance in a side street (Roanoke, Va.). Figure 1 shows the unsightly congested system that was rebuilt and now looks much better, as indicated by figure 2.

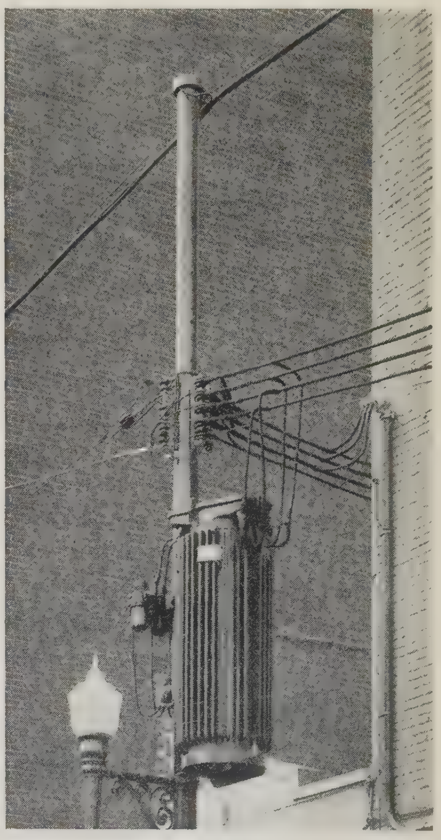


Fig. 2. The same system shown in figure 1 after rebuilding

It might be of interest to mention that the first step type regulator to be installed in this country was on a line of one of the American Gas and Electric Company subsidiaries, in this case the Appalachian Electric Power Company, near Roanoke, Va. Figure 3 shows this regulator, which went into service in 1932. Since this first installa-

tion was made the use of step regulators has grown rapidly and many different types of step boosters and regulators have been developed. Not only are these step type regulators cheaper, making it possible to justify their use in many cases where induction regulators could not be justified, but also they are much simpler to maintain. Writing in 1933 about step-type regulators, the writer stated that "the step regulator may not entirely replace the induction regulator but it is hard to think of many places where it will be possible to justify the choice of the complicated, fragile, and rather expensive induction regulator against the simple, rugged and much less costly step regulator. This will be particularly so after the step regulator has had a few more years of development and extension in current and voltage ranges."

It is interesting that the development has taken place exactly along these predicted lines, and that the step regulator has been extending its field of application. The writer believes, as does Seelye, that it is an economical and serviceable tool in the hands of distribution engineers, and that its use is bound to grow in the future.

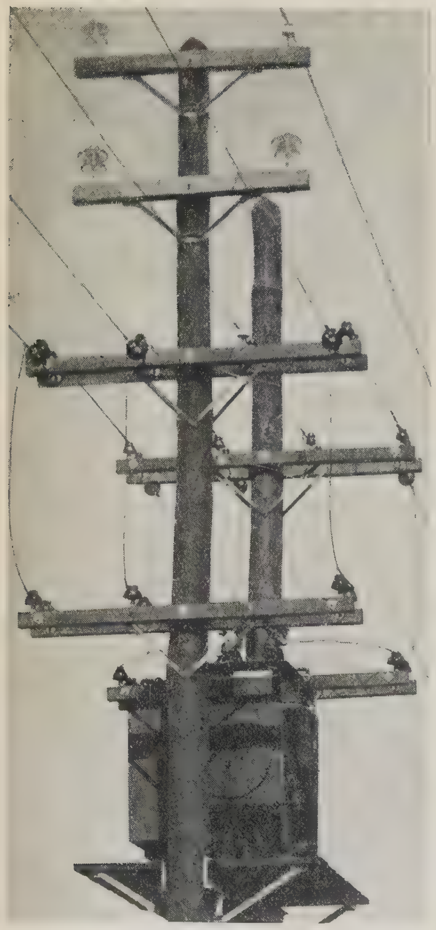


Fig. 3. A 1,080 kva "step" regulator in use on the Fincastle (Va.) line

Outdoor metering is, and has been, a particularly live subject in the general distribution field during the past 4 years. For some 10 years prior to 1932 the idea of outdoor metering installations was considered, and several thousand such installations were made, but the outdoor enclosures (there were no universal outdoor meters at that time) were clumsy and expensive, costing about 4 dollars an enclosure.

During the depression the diversion problem led engineers to the outdoor installation, and that in turn led to the necessity of development of an outdoor enclosure that was more economical and more generally applicable. Figure 4 of this discussion is typical of the steel enclosure developed about 1932. This type of installation was adopted as standard in 1932 on the system of the company with which the writer is associated. Subsequently the problem was studied further, and better appearing enclosures were developed, but many of those working closely with the problem felt that a final solution could not be obtained until a universal outdoor meter was developed. This finally came about in 1934. Figure 5 of this discussion shows a typical installation with the outdoor meter and the continuity of the service drop and service entrance cable is evident, which not only improves the appearance but also adds immeasurably to the installation from a diversion safety standpoint.

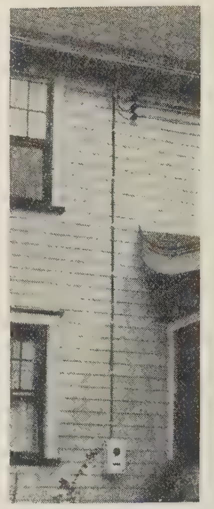
During the last $3^1/_2$ years about 150,000 meters have been placed outdoors and at the present time approximately 50,000 meters per year are being changed from indoor to outdoor locations.

It appears to the writer that distribution has received altogether too little attention before the Institute. There have been people who have imputed some sinister motive to this meager presentation of data on the problem. In this the writer believes that they were mistaken. Probably it was due to a timidity on the part of engineers in offering distribution material for Institute programs, and possibly also to a lack of encouragement on the part of those in the Institute who have felt distribution and economics are so closely interwoven that it was perhaps best to avoid the entire problem. This too is a mistaken idea. In fact, there is no engineering subject in the power industry today that is so alive and on which so much work is being done, and on which so much work will have to be done. The progress that has been made in the last 5 years has been very gratifying, although it sometimes has appeared to be slow. The task, however, has been enormous.

J. W. Bennett (Western Massachusetts Companies, Springfield): The design of a system of power distribution for a particular locality must, as the author points out, take into consideration the conditions as they exist in that locality. A system that would prove best for one section may not be at all suitable for a similar area where certain local conditions differ.

In the writer's opinion, the system of power distribution for any area or type of load should be flexible. There is no economy, and certainly there is no engineering justification, for building a system that will take care of existing requirements, no matter how well it may do this job, but that may require complete rebuilding in a few years because of changing load conditions. Such a system may be low in first cost but very expensive in final cost. In designing a system of power distribution, the engineer should endeavor to anticipate changing conditions so far as possible, and should arrange the system so that in the event of a new set of conditions the transition to the proper type of supply may be made without excessive obsolescence of existing equipment.

Several years of experience in the design of distribution systems for all types of load, both urban and rural, have convinced the writer that all types of systems, from the simple radial one to the relatively complicated underground low voltage network, have definite applications. Careful engineering study usually will reveal the one best system for a particular combination of conditions.



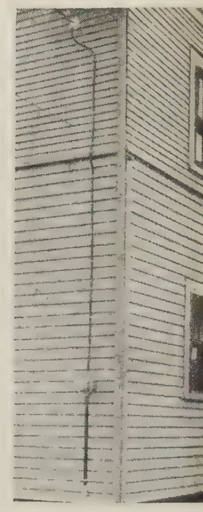


Fig. 4 (left). Typical outdoor steel meter enclosure in use in 1932

Fig. 5 (right). A new type of outdoor meter installation using a detachable meter

Seelye's statement regarding the size of transformers and secondary copper for overhead distribution is of considerable interest. During the past 5 or 6 years, the writer has made some extensive studies of this problem and has found that for the loads generally encountered on the overhead single phase system, number 2 copper conductor with 15 kva transformers spaced approximately 800 feet apart gives the most economical arrangement. This may be modified somewhat with a different type of secondary configuration.

The author's statement regarding the importance of competent engineering design for the distribution should be emphasized. The problems in distribution design frequently are more varied and complex than those encountered in any other branch of central station engineering, and if the most economical and efficient system of distribution is to be obtained, proper engineering study is necessary. The amount of engineering thought given to distribution systems has not been sufficient in the past.

W. B. Elmer (Edison Electric Illuminating Company of Boston, Mass.): In several places in this paper the appearance of a plant is mentioned. It is stated that modernization should serve to improve appearance,

except that style should be avoided. The writer believes that whenever an attempt is made solely to obtain improved appearance, and elements are added or modifications made in apparatus or equipment for this purpose only, apart from considerations of utility, economy, and safety, very little is gained.

Many years ago, The Edison Electric Illuminating Company of Boston, adopted a street lighting bracket consisting of a pipe with 3 bends, a scroll with 3 curlicues, and a medallion with the company's initials in large relief letters. This was adopted in the days when rococo scroll work of the Louis XV period was in vogue. It was distinctly an attempt at style.

During the past year this old design has been abandoned and a new and simplified bracket has been adopted. The new bracket consists of a simple horizontal pipe parallel to the crossarms, a slanting support that is parallel to the crossarm brace, and one exceedingly plain curving element to support the other 2 elements. This harmonizes with the conventional pole construction and is not marred by attempts at style. It never can become antiquated in appearance until more effective mechanical elements or arrangements are discovered.

Advertising signs must of necessity reflect current style vogues. Architectural treatment compels the use of periods, types, and styles. The modernistic office building has thrown off practically all surplus ornamentation, yet remains a distinct type, subject to obsolescence, because it does represent a distinctive mode of design.

Beauty is largely a matter of opinion. The author's "new style distribution construction for better appearance" is, in the opinion of the writer, unsymmetrical in appearance, not primarily utilitarian in purpose, and since it is no cheaper than standard construction, it has slight justification except that it is different.

W. R. Bullard (Ebasco Services, Inc., New York, N. Y.): H. P. Seelye has given a very thorough description of modern distribution practices that promote economy and reliability of service. One type of system of long standing, however, which he failed to mention and which is receiving more and more attention, because of its lower cost, higher efficiency, better regulation, fewer primary circuits, and absence of distribution substations, is that of direct radial primary distribution at subtransmission voltages, such as 11 kv and 13.2 kv. The writer is not aware of any case of failure of the system to provide adequate service reliability, that is, service of the order to be expected from any radial system. The same is true with regard to the question of safety to the public and to workmen. The inherent simplicity of this system, both as regards its design and from the operating standpoint, commends it for conditions in which the type of service obtainable from a radial system is satisfactory, and where a transformation can be eliminated by its use.

The writer is much interested in Seelye's description of recent farm practices and subscribes to the methods of reducing costs he mentioned. The design illustrated in his paper involves 2 live conductors for single phase service. This naturally is more expensive than lines having one live conductor and one grounded conductor. This latter type of line is simpler. It permits the elimination of crossarms and the use, instead, of pinnacle pins with the ground conductor uninsulated and supported by a suitable metal bracket or clamp. Where lightning arresters are used, this type of line also permits the elimination of one set of these accessories. By the use of the higher primary voltages, it has adequate capacity for all ordinary needs.

In discussing bare wire, it has been suggested in the paper that improvement in weatherproof covering possibly should be made for congested districts instead of taking a step in the other direction and removing all covering. The writer disagrees with this viewpoint. To insulate line wire adequately requires something more than merely improving the weatherproof covering; furthermore, when proper insulation is added, the line cost is increased appreciably. A better solution is to provide adequacy of construction, including careful attention to conductor strength and to proper sags and tensions; also to maintaining proper clearances. The removal of all covering is an aid toward the accomplishment of these measures. Of course, under some tree conditions where clearances cannot be maintained, it is necessary to use tree wire or cable. The use of such material should be held to the minimum consistent with service reliability, however, any other available methods, such as tree trimming, and alley arm construction, being used in preference where it is practicable.

In discussing lightning protection, Seelye has not mentioned as a possible solution the use of ordinary open air gaps without arresters, but combined with automatic rapid reclosure of primary circuits. Fast reclosure is now being extensively applied and has been found to provide a means for limiting most circuit tripouts to momentary interruptions of negligible effect on service. Thus, using gaps to minimize failures in circuit equipment may accomplish a considerable reduction in number of prolonged outages, possibly at the expense of an increase in the number of momentary tripouts, the latter, however, being of relatively small concern from the standpoint of service. An air gap is simple, inexpensive and not subject to being blown up by an excessively large surge or direct stroke. Also during operation it has very low impedance and although experience is not extensive, it seems to indicate that almost perfect protection to equipment can be secured by adopting proper gap settings, and using the interconnection of grounds mentioned by the author.

C. A. Corney (Edison Electric Illuminating Company of Boston, Mass.): The company with which the writer is connected has in service 2 of the 3 types of distribution systems utilizing the smaller sizes of transformer units mentioned by the author, namely, the radial substation with 2 transformer banks supplying a bus from which feeders are served, as shown in figure 1*b* of the paper, and a 4 unit primary network similar to that shown in figure 1*c* of the paper except, that each transformer unit is supplied by a separate transmission line. Both of these systems are operating without difficulties, the load division and voltage conditions being excellent. The only primary network system mentioned by the author is a single transformer unit type. Although this may be the ultimate network picture, it may not necessarily represent the most economical initial arrangement as the writer's studies indicate that under certain conditions a primary network may be developed initially to relieve an overhead substation by starting with a double ended unit consisting of 2 transformers and circuits running in different directions. The double ended units later may be converted to single units by the removal of one of the transformers and combining it with an additional switching unit for installation at some other load center of the network area. Economic and voltage regulation studies, furthermore, indicate that for many urban and suburban load densities the single transformer unit with 4 circuits should have a larger transformer than is used ordinarily. Transformer capacities of the order of from 2,500 to 3,500 kva would seem to be better suited to these conditions. There is also a question of whether 250,000 kva circuit breakers and network units may not be too heavy for the duty. It appears possible to design network units so that breakers, say of 100,000 kva capacity, could be installed initially and later readily replaced with units of higher rating, the replaced units being used in locations where the duty is not severe.

The author mentions interleaving transmission lines and thereby reducing the necessary reserve capacity in lines and transformer units. This idea may be carried farther by introducing automatic or nonautomatic circuit breakers into transmission lines supplying the network where these lines are or can be energized from both ends.

The so-called "common neutral" system is not mentioned. The Boston company has for many years operated an ungrounded 2,300 to 4,000 volt primary distribution system. After a trial period of from 2 to 3 years in several localities the company is now actively proceeding to ground the primary neutral at all substations. This makes possible the adoption of the common neutral in both overhead and underground construction, thus eliminating the neutral wire of the primary system and using the secondary wire as a common neutral. This system effects large economies in the reduction of circuit miles of wire, in the elimination of one arrester and one fuse per transformer, and one pole of switching equipment. (This last economy applies only in those instances where the change to the common neutral is made from a previously isolated neutral system.) The use of sheath neutral return for underground construction also is a feature worthy of considering, but it is not necessarily dependent upon the adoption of the common neutral. Brief reference is made to the spacing of primary wires and its effect on service continuity. The experience of the company with which the writer is connected indicates that such increased spacing will materially improve continuity due to a decrease in the possibility of wires slapping together in the wind and of tree limbs permanently resting on the wires. The use of one or more insulated wires for primary construction is mentioned but should be considered more closely in relation to the spacing. The elimination of one wire from the primary arm permits greater spacing.

No mention is made of series versus multiple street lighting, a question now be-

ing considered carefully by the writer in view of a proposal to convert some 5,000 gas lamps in the city of Boston to electric lamps. It appears that in many instances multiple lighting with suitable control has advantages over series lighting, not the least of which is the removal of the necessary high tension series wires from the poles, thus making pin space available on the primary arms.

The banking of secondaries is being studied, ringed primaries have recently been adopted in numerous locations.

About 12 or 15 25 kva surge proof transformers, with secondary circuit breakers equipped with signal lights are in service. It is too early to say how successfully these transformers fulfill their purpose in being completely self protecting.

The studies by the Boston company show that at any load density between 7.5 kw per thousand feet and 45 kw per thousand feet, number 4 or number 2 wire using 10, 15, or 25 kva transformers is the most economical. Number 2 wire has been chosen standard in Boston as in Detroit.

There is little call for farm lines in the territory of the company just referred to, so that construction of this class in any considerable amount is quite unlikely; consequently, this matter has not been investigated in the detailed manner used by many companies.

For primary extensions of from 500 to 1,000 feet on private property the possibility of single conductor underground construction is being considered. Some experience has been obtained with single conductor sheath return cable in overhead primary extensions on rear lot lines suspending the cable on messenger construction. Messenger and sheath serve as grounded neutral return. This practice is less expensive than heavy secondaries where the extension is in excess of from 5 to 6 sections. It eliminates the use of exposed primaries on rear lot lines and also saves on tree trimming and provides excellent voltage conditions.

The only use of bare conductors on the Boston system is for secondary neutral conductors underground. In this case, the wires are tinned. For many years a form of buried secondary construction known as "split fiber" has been used, in which ordinary weatherproof line wire is imbedded in fiber pipe and encased in an insulating compound. The whole structure is covered by a treated wood plank. In this construction each outside wire is encased in a separate fiber pipe, the neutral being buried in the ground between pipes. A similar type of low cost underground secondary distribution in which a single fiber pipe contains both outside wires, a neutral wire and a multiple street light control wire is being developed. All wires are insulated with 600 volt rubber and braid, except the neutral conductor, which is bare. Recently collected data indicate only slightly greater cost than equivalent overhead construction if trenching and backfilling are done by the property owners.

The present average impedance of 2.7 per cent for transformers from 3 to 37.5 kva is satisfactory. As only a small part of the drop due to motor starting is in the transformers, their characteristics should not be changed further unless there are advantages to be gained. The writer's studies indicate that overhead transformers should be loaded to at least 150 per cent of their name plate rating during winter peaks, if voltage regulation permits it. Overhead transformers on most systems are not properly loaded, the tendency being to magnify anticipated load and install too large a transformer. There is also a failure to appreciate the full effect of diversity, especially for electric range load.

Lightning arrester protection for distribution transformers utilizing interconnection between the arrester ground lead and the secondary neutral has materially reduced outages from fuse blowing and burnouts. Interconnection is being very generally applied throughout the system wherever arresters are considered necessary.

The new sequence and outdoor metering are being applied to new overhead services in our territory, and the new sequence with indoor meters is being applied quite generally except where more than 4 meters are involved.

The writer believes that an adequate and competent engineering staff should be retained for the handling of distribution problems. The investment in distribution warrants close attention to details of engineering design and construction.

H. P. Seelye: Although most of the discussion indicates a general agreement with the features of modernization presented in the paper, there are a few points of criticism that should not be left unanswered. W. B. Elmer takes considerable exception to the plea for better appearance and to the example of a step in that direction. He confuses the suggestion for sound architectural design with the idea of style or ornamentation, which is not an essential accompaniment, and which was specifically criticized in the paper. Usually there are many alternative methods by which utility, economy, and safety in a structure may be accomplished, but some will be of better proportion and arrangement than others, and hence more pleasing to see. It may be preferable in some cases to spend a little extra for this effect, if a much greater expenditure for underground lines may be avoided. The example shown was not, as he thinks, merely an attempt to do something different, but was the result of a study of the many factors involved, including reduction in amount of excess material and space occupied, accessibility of wires to workmen, and economy, as well as betterment of appearance.

The use of the common neutral system recommended by C. A. Corney undoubtedly effects an economy on some systems. On the contrary, however, there are many who believe in the operating advantages of the ungrounded delta system, and it would not be fair to say that the modern trend was toward the common neutral, except perhaps for systems with the neutral already grounded.

W. R. Bullard mentioned the economy of grounded neutral circuits instead of 2 line conductors for farm lines. Although the saving in cost of fuses and arresters is real and may be appreciable, the difference in cost for the remainder of the construction is insignificant. The type of system that is being extended to render the service will be the governing factor in most cases.

Bullard's statement that adequate improvement in insulation on weatherproof wire can be accomplished only by appreciable increase in cost is questioned. Adequate insulation for protection against occasional contacts is quite different from adequate insulation for continual and continuous contact in conduit and similar locations. Several new types of covering have been brought out recently which give promise of being satisfactory for the purpose without introducing a major increase in cost.

Lightning Protection for Transformers

Discussion of a report of the A.I.E.E. transformer and lightning arrester subcommittees published in the January 1936 issue, pages 53–6, and presented for oral discussion at the modernization of distribution systems session of the winter convention, New York, N. Y., January 30, 1936.

I. W. Gross (American Gas and Electric Co., New York, N. Y.): The authors of this paper state "the method (of protecting transformers) using lightning arresters and ground wires, presents as high a grade of protection as can be suggested for substations." Such an installation was made 2 years ago on a 132-kv 30,000-kva transformer bank at a tap line station on a system of the company with which the writer is connected with the added features of a derated arrester and a transformer insulated below normal. It is believed that the features of this installation may be of interest to those using or considering using this general protective scheme.

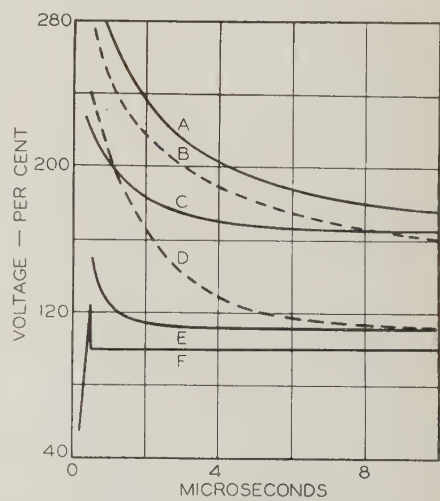


Fig. 1. Insulation co-ordination characteristics (positive polarity basis) of a 132-kv 30,000-kva transformer bank

A—Line entrance insulation
B—Switch insulators
C—Transformer bushing
D—Transformer test gap
E—Safe strength of transformer
F—Lightning arrester protective level

A single ground wire existed at the peak of the conventional 2 circuit tower over the entire line. At the substation 3 ground wires had been placed from the last tower to the station structure on each side of the structure. The change made in the ground wire layout was to remove the middle wire from the towers adjacent to the station and re-

place it with one ground wire supported at the 2 adjacent towers and suspended a distance of 55 feet above, but not directly connected to, the station structure.

For a distance of approximately 0.6 miles on each side of the station, ground rods and counterpoises were installed to lower tower footing resistances. Before these were installed the resistances ranged from 4 to 34 ohms; afterward they varied from 3.3 to 7.0 ohms. Table I of this discussion shows the extent of the work done in reducing ground resistances. Work was done on 5 of the 8 towers involved. At each tower 4 10 foot and rods 2 75 foot counterpoises were used; a continuous counterpoise between 2 towers was used and a 300 foot counterpoise to a nearby creek was installed in one case. Most of the ground rods and all of the counterpoises were treated with 100 pounds of salt each. The 5 ohm objective per tower was exceeded at only 2 towers.

The co-ordination of the transformer insulation and its associated equipment is shown in figure 1 of this discussion, based on the best impulse information available. The lightning arrester was derated from standard practice, and its protective level was taken as a basic level. The transformer insulation was co-ordinated with the lightning arrester, and full advantage of the arrester was taken by placing the arrester on the transformer tank, thus making physical connections as short as possible. The transformer bushings were one voltage class below the standard 132 kv rating. Insulators on switches and at the line entrance were the customary standard, the same as used at that station in the past.

Based on the data in figure 1 of this discussion, it is indicated that full protection against transformer failure due to lightning voltages should obtain, within the present knowledge of natural lightning phenomena and lightning arrester performance. The fact that this transformer bank has operated successfully through 2 lightning seasons (the last one very severe in that location) gives weight to the belief that the principle of protection on the foregoing basis is sound. The performance over a 2 year period, however, is too short a time on which to draw the conclusion definitely that the protective scheme will be infallible under all conditions of overvoltages encountered in service.

Although this installation is interesting from the technical protection point of view, its economic aspect is equally important. By taking advantage of the better understood performance of the lightning arrester and transformer impulse strength, the cost of the transformer alone was reduced more than $^1/_5$ below the so-called standard transformer.

Modernization of Transmission Lines

Discussion of a report of the A.I.E.E. lightning and insulator subcommittee published in the January 1936 issue, pages 12–18, and presented for oral discussion at the modernization of distribution systems session of the winter convention, New York, N. Y., January 30, 1936.

S. K. Waldorf (Pennsylvania Water and Power Co., Baltimore, Md.): In the summary of experience with expulsion protective gaps given in the paper, reference is made to that on a 69 kv double circuit steel tower line. The transmission line in question is 17.5 miles long. In reporting to the committee, no mention was made of a 13 mile wooden pole line connected to the steel tower line, for there is no evidence that the pole line affected the performance of the tower line in any way. Probably because of the form in which the data on the tower line were submitted to the committee, it has been interpreted to make the performance of the gaps appear better than it was. The expulsion gaps have been on the line only about $^3/_4$ of one lightning season, instead of 2 whole seasons as indicated in the paper. The installation was completed on June 16, 1935, and by July 1, 1935, the trouble due to short relay tripping time had been corrected. During this 2 week interval, 2 of the gap tubes flashed over externally causing 2 tripouts, and one additional tripout was caused by neutral ground current. The neutral ground relays have a minimum tripping time of 9 cycles (0.15 second) indicating that there was a flashover to ground that was not cleared by the expulsion gaps. There were some additional tripouts during this period due to insufficient time delay in the operation of the line impedance relays, but they cannot be charged to any shortcomings in the gaps themselves. After the time delay of the line impedance relays had been increased to 5 or 6 cycles (from about $1^1/_4$ cycles), there were 2 more externally flashed tubes causing tripouts, and 2 additional tripouts by neutral ground currents for which no burned tubes were found. The summary for the period of installation is 4 tripouts due to externally flashed tubes and 3 tripouts due to protracted neutral ground currents for which no burned tubes were found.

The writer's experience with transmission lines in general has not been in accord with a contributor's opinion quoted in the paper "that absolute immunity from lightning troubles is almost impossible to obtain." That claiming absolute immunity to anything so erratic as lightning would be foolish is acknowledged for a line may go through several lightning seasons without trouble and then perform badly, but the writer's experience indicates that immunity can be obtained by shielding line conductors with 2 overhead ground wires and co-ordinating tower footing resistances with line insulation.

With double continuous buried counterpoise wires of the type shown in figure 4*E* of the paper discussed the writer has been able to bring all tower footing resistances of a 69 kv line to less than 20 ohms (average 9 ohms) where formerly they were as high as 525 ohms (average 133 ohms). The present tower footing resistances were measured with only the adjacent spans of counterpoise connected to the measured tower, and not with the full length of counterpoise connected together from one end of the line to the other. It is believed that this line will show good lightning performance because of the care taken to shield the conductors against direct strokes and to co-ordinate tower footing resistances with insulation strength. The operating experience on this line with the counterpoise and 2 overhead ground wires in place thus far has been only about $^1/_3$ of the 1935 lightning season. There were no outages during this period, whereas formerly almost every storm caused at least one outage.

There are 2 other lines, one a 132 kv line and the other a 230 kv line, that passed through 1935 without any flashovers. The good performance was not due to the mildness of the lightning in the vicinity of these lines, as shown by the many strokes recorded on the surge crest ammeter links mounted on the towers of these lines, but instead to good shielding and co-ordination of tower footing resistances and insulation.

For practical purposes, lightning proof transmission lines operating at 69 kv and higher seem to be within reach.

P. L. Bellaschi (Westinghouse Elec. and Mfg. Co., East Pittsburgh, Pa.): Improved methods of measurement and testing have assisted materially in bettering the lightning performance of transmission systems; in fact, the prospects of finding a solution to the lightning problem have been related to the extent to which lightning phenomena have been investigated by such means.

Further progress undoubtedly will depend upon continued studies along these fundamental lines. Contributing to this future program of fundamental investigations, the lightning stroke generator is now available. ("Lightning-Stroke Generators," P. L. Bellaschi. *Elec. Jl.*, June 1935, p. 239, figure 5.) It comprises laboratory apparatus capable of delivering a steep fronted, high voltage wave followed in microsecond sequence order by a current discharge of lightning stroke intensity. The combined voltage and current thus produced simulate in effect the dielectric and dynamic stresses developed by natural lightning when it discharges to wood poles, insulator strings, and other transmission line equipment.

L. G. Smith (Consolidated Gas, Electric, and Power Company of Baltimore, Md.): This paper deserves commendation for data of this type are necessary to the industry. All operating companies have many miles of

Table I—Reduction of Tower Footing Resistance at a 132 Kv Substation

Tower number	142	141	140	139*A*	Substation	139	138	137	136
Tower span, feet	1,000	1,400	550	589	417	994	258	1,415	
Tower footing resistance (1928)	12.5	11.1	4.2	36.0	0.2	4.8	18.0	15.3	4.1
Tower footing resistance (1934)	13.9	12.0	4.0	34.0	0.2	4.6	17.9	16.0	4.2
Ground rods added	4	4		4			4	4	
100 pounds salt per rod	No	Yes		Yes			Yes	No	
Counterpoises added (75 feet each plus 100 pounds of salt)	2	2		2[I]			2[II]	2[II]	
Final tower footing resistance (1934)	7.0	5.2	4.0	3.3		4.3	4.4[II]	4.4[II]	3.9

I. Also 300 feet of counterpoise to and along a creek.
II. Continuous between towers 138 and 137.

existing lines, but normally they build relatively few miles of new line each year. Therefore, even the realization of the dream of a lightning proof line for a new line would have but little effect on the lightning performance of the system as a whole. Unless existing lines can be reconstructed without excessive expense, very little real improvement can result in reducing outages due to lightning.

Except for the 110 kv line mentioned, the operation of transmission lines at various voltages using gap protection is quite encouraging. In the case of the 110 kv line further details would be interesting in order to determine the cause of the apparent increase in outages after the application of the tubes. It is important, therefore, to determine whether the cause has been due to external flashover, improper relaying or improper tube application.

Although the use of these tubes bears considerable promise, there are apparently 2 difficulties to overcome: (1) elimination of external flashovers, regardless of whether they are due to weathering of the outside of the tube or due to lack of co-ordination between internal and external flashover for all wave fronts; (2) the life of the tubes due to weathering. This is important, for successful operating life must be reasonably long because of the fairly high initial cost of tube installation.

Tests made in the "weather-o-meter" indicate that the life of these tubes so far as weathering is concerned depends solely upon the protective coating, whether it be a paint or a wrapping of phenol resin compound.

Although no tube applications have been made on lines of the range of voltage considered by the subcommittee in its investigation, some tube applications on several lines operating at 13.2 kv have been made. In view of the slight difference in the design of lines operating at voltages of from 13.2 to 45 kv, a few points might be raised in connection with the operation of tubes on several 13.2 kv lines during 1935, on the system of the company with which the writer is associated. During the 1935 lightning season 3 lines were so equipped.

Table I of this discussion outlines the 1935 experience for the 3 lines so equipped.

On line number 3 there was one tripout due to lightning arrester failure at one of the substations, but there was none due to line trouble. Because of accidental short-circuiting of the external gap, 2 tubes were burned up that faulty design on certain types of pole structures subsequently has been corrected.

On lower voltage lines, namely, those operating at 45 kv and below, it is highly desirable to obtain operating experience with various tube spacing. Approximately 7 miles of pole line now are equipped with tubes on every other pole. For the purpose of comparison another line this year is being equipped with tubes on every fourth pole. On intermediate poles an attempt is being made to obtain the maximum practicable insulation level. It is hoped that further data can be obtained on the results obtained with various tube spacing, so that it will be possible to equip the minimum number of poles on a given line with these expulsion tubes in order to keep the costs within reasonable limits.

It is essential that all operating data on expulsion protective gaps be accumulated from the various companies using them and compiled for the benefit of the industry as a whole.

Prominence has been given to the maximum use of wood insulation, such as wood crossarm braces and wood guy strain insulators; however, care should be used in applying wood insulation, otherwise considerable money may be spent without obtaining any appreciable increase in the insulation level of the line. Another point must be considered, particularly on higher voltage lines; namely, if the insulation level is raised too much by the use of wood, splitting and shattering of the wood may cause outages of long duration when flashovers do occur.

On a 66 kv wood pole line that was designed for future conversion to 110 kv several poles were split by lightning, resulting in dropping the top conductors to the lower ones, and producing several outages of long duration. Since the line was a new one it was thought that these troubles were partly due to the fact that the poles were fairly green. As a result, a pole ground wire was installed on each pole and was quite effective for several years. After several years operation the pole ground wires were removed, because of the belief that the poles then were well seasoned. However, in 1934 2 prolonged outages were caused by poles being split by lightning. As a result of this experience the pole ground wires again were installed and undoubtedly will be installed on any future 66 or 110 kv wood pole lines. If this experience is typical, and the use of a pole ground wire is necessary for protection from pole splitting, the use of wood crossarm braces will have a material effect in increasing the insulation level of the line.

Using a 12 foot 8 inch crossarm with an insulator string suspended 6 feet out from the center of the pole, the phase to ground flashover with 6 insulators per string is increased from about 835 to 1,025 kv, or an increase of approximately $^{1}/_{4}$, by the substitution of wood crossarm braces for steel ones. Tests indicate also that to preserve this insulation level guys should be maintained at least 6 feet from line conductors and 3 feet from fittings at the top of insulator strings.

The following illustrates the necessity of applying wood insulation only after tests have been made. About a year ago recommendations were made regarding the use of wood pole line then being built. Subsequent to that time tests were made with different types of structures, with the result that a recent inspection of the construction indicated that some of the wood recommended a year ago is ineffective in raising the impulse level. Since the spacing of conductors and insulation level of the 13.2 kv lines are not different from lines operating up to 45 kv, the conclusions reached from impulse tests made on several types of the 13.2 kv construction may be of interest. The phase spacing of conductors was accepted as the limitation upon impulse strength. With 4 foot spacing, the phase to phase impulse strength for 2 conductors on pin type insulators without any crossarm braces was found to be approximately 700 kv using a 1.5 x 40 wave. Therefore, it was decided that a logical improvement was to increase the impulse strength from phase-to-phase and phase-to-ground to this value by the use of wood where necessary. Figure 1 of this discussion illustrates this for one type of construction. It will be noted that guys as high as 1 foot below the lower crossarm brace do not require wood strain insulators; however, guys

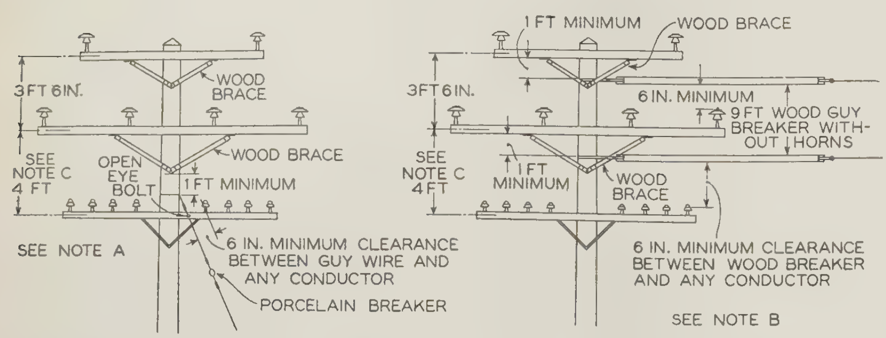


Fig. 1. Example of upright construction pole guying for double circuit lines operating at from 13 kv to 33 kv

Note *A*—Point of attachment of anchor guy may be made as much lower than the point shown as practicable, depending on degree of corner angle and strain on pole

Note *B*—Single guy attachment may be made at either location shown; for heavy guying, attachments may be made at both locations

Note *C*—Spacing between 4 kv and 13 kv arms usually is 4 feet on existing construction. Preferable spacing is 5 feet, which should be maintained on all new construction

Table I

Line	Circuit	Length, Miles	Tube Operations Phase *A*	*B*	*C*	Ground	Tripouts, 1935	Tube Spacing	Tripouts, 1934 Without Tubes
1	Single	3.5	8	2	3		0	Alternate poles	4
2	Double	3.4	10	13	10	6	0	Alternate poles	5
3	Double	0.62	7	12	6	2	0	Every third pole	New line 1935

above this point require wood strain insulators installed close to the pole, otherwise the phase-to-phase flashover will be reduced to about 400 kv. Figures 2 and 3 of this discussion show conclusions for 2 other types of construction.

In the discussion of the results obtained by the use of counterpoise on high voltage transmission lines, it is of interest to know the type of shielding used on the various lines for which data is given. Where the counterpoise has been added to existing lines it is quite probable that the type of shielding now recommended by certain transmission engineers does not exist. In theory, at least, the outages due to lightning on a transmission line depend upon: (1) the degree of shielding; (2) insulation level of the line; (3) tower footing resistance.

On existing lines it is frequently impossible to change items (1) and (2); however, by the installation of the counterpoise it is possible to vary item 3. It would be interesting, therefore, to know the probable results that will be obtained for a given line by varying the only possible variable, that is, the tower footing resistance.

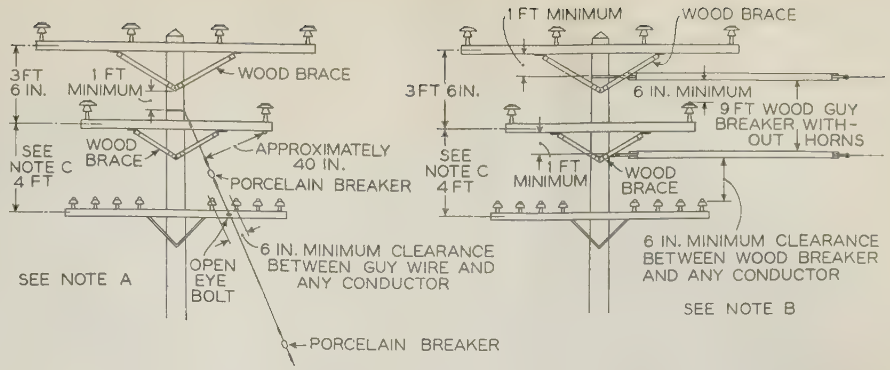


Fig. 3. Example of inverted construction pole guying for double circuit lines operating at from 13 kv to 33 kv

Notes *A*, *B*, and *C*—See corresponding notes for figure 1

J. W. Jones (Philadelphia, Pa., Electric Co.): The paper outlines in an interesting and instructive manner numerous methods of improving performance of existing lines. Unfortunately, the protective value and practicability of some of these methods are uncertain, because, among other reasons pointed out in the paper, little information is available regarding operating experience. Although some experience of the company with which the writer is associated was used in preparing the paper, additional information and comments may be of interest.

1. Changing insulation of the Conowingo-Plymouth Meeting 220 kv lines involving 116 circuit miles from 14 to 16 units was followed by a reduction in outages due to lightning from an average of 4 per year with the original insulation to an average of 2 per year for 6 years with increased insulation. This reduction of $^1/_2$ is considerably better than the average of 8 per cent given in the paper for 220 kv lines in general.

2. With regard to deionizing gaps, several pole top switches on 33 kv lines, which are particularly susceptible to lightning trouble, have experienced no lightning trouble since installation of deionizing tubes. However, during the first year of operation serious erosion of the outsides of the tubes was caused by leakage current, apparently resulting from the unusual manner in which the tube was suspended from the line conductor by means of a single unit strain insulator shunted by a spark gap.

3. With regard to the use of wood poles for impulse insulation, detailed study of lightning troubles on 33 kv wood pole lines of the company with which the writer is connected shows that poles with vertical ground wires or guys from pole top to ground, with only ordinary strain insulators, have a rate of lightning trouble ranging from 2 to 3 times the rate for other poles. In view of predominance of lightning trouble on such poles, guy wires have been lowered, where possible, to 1 or 2 feet below the crossarm brace and gaps connected in the vertical ground wires on several hundred poles. Experience during the last lightning season with these poles shows no appreciable reduction in the rate of lightning trouble, and in several cases the poles were splintered or burned seriously about the gaps, indicating that 2 feet of wood pole insulation is not sufficient to effect much improvement.

L. V. Bewley (General Electric Co., Pittsfield, Mass.): The efficacy of the various means of improving the lightning immunity of transmission lines, as brought out in this paper, is in full accord with theoretical predictions. Thus, the lightning current necessary to cause a flashover is given by

$$I = \frac{V}{(1 - CF)R}$$

where

V = impulse flashover voltage of insulation

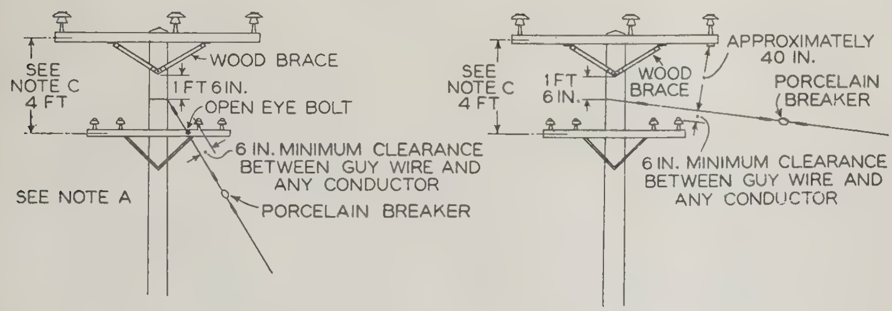
CF = coupling factor between ground wires and line conductors

R = tower footing resistance

Now it is clear, to make flashover improbable for high lightning currents, that (1) The impulse flashover of the insulation should be high, which may be brought about by: (*a*) additional insulators; (*b*) wood crossarms; (*c*) grading shields.
(2) The coupling factor should be large, which may be brought about by additional ground wires. For instance, the coupling factor varies with the number of ground wires within the following limits:

Number of Ground Wires	1	2	3
Coupling factor....	0.20 to 0.40..	0.35 to 0.55..	0.45 to 0.65
$(1 - CF)$ ..	0.80 to 0.60..	0.65 to 0.45..	0.55 to 0.35

(3) The ground footing resistance should be low, which may be effected by: (*a*) addi-



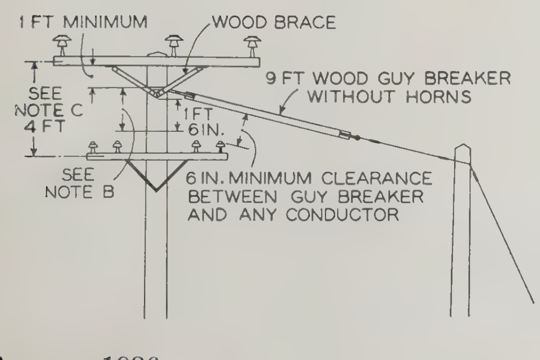


Fig. 2. Example of pole guying for single circuit lines operating at from 13 kv to 33 kv

Note *A*—See note A for figure 1

Note *B*—When guy attachment comes within this space install guy as shown with wood guy breaker at pole

Note *C*—See note C for figure 1

tional ground rods or (*b*) counterpoises.

Comparing these rational conclusions with the information contained in table I of the paper, it is seen that the agreement is complete.

In a recent paper "Flashovers on Transmission Lines" (ELEC. ENGG., v. 55, April 1936, p. 342–54) the writer has made this simple formula (with minor refinements), in conjunction with a statistical curve on lightning current severity and frequency of occurrence. These data form the basis for a detailed study of flashovers on lines, and their segregation into single phase, 2 phase, and 3 phase, as well as single and double circuit outages. Some of the pertinent conclusions of that study are:

1. Reduction of tower footing resistance usually is more effective in reducing flashovers than is additional insulation.

2. A system of 2 ground wires is superior to one ground wire for 3 reasons: (*a*) the shielding is more complete; (*b*) the coupling is greater; and (*c*) the net surge impedance is less.

3. Wood pole flashovers are likely to be predominantly 3 phase, and higher voltage surges are permitted to reach the station.

Edward Hansson (Pennsylvania Water and Power Co., Baltimore, Md.): The subcommittee on lightning and insulators is to be congratulated on the excellent summary submitted in its reports. Such a summation of efforts made on various systems in order to improve operation will do much to provoke thought on the subject and bring out the salient features of those methods that have proved to be effective.

The writer is impressed by the tendency of some engineers to give too much weight to operating records covering comparatively short periods and a warning should be sounded that such short term records cannot be considered to be any definite proof of a tendency one way or the other. This is true even if the records for one year after an improvement has been made show a considerable improvement. In order to prove this statement, data from 4 different double circuit lines, covering a period of from 10 to 18 years, are presented in table II of this discussion. These records show that by comparing the outages for single years it is possible to get ratios as high as 15 to 1, and even by taking 5 year periods the ratios may be as high as 2 to 1. Table II shows comparisons for these lines, made on the basis of single years and groups of 2, 3, 4, and 5 consecutive years. These comments are submitted in order to prevent investigators from becoming overenthusiastic about short time experiences.

Table II—Maximum Ratios of Outages for Different Periods

Circuits	Number of Years 1	2	3	4	5
A	4.5	1.6	1.6	1.5	1.3
B	8.0	4.5	2.0	1.5	1.2
C	7.0	3.0	1.5	1.4	1.2
D	15.0	3.3	3.0	2.5	1.9
E	5.5	2.3	1.5	1.1	1.1
F	3.8	1.9	1.4	1.3	1.1
G	10.0	2.2	1.7	1.2	1.3
H	4.3	3.1	2.0	1.4	1.6

Modernization of Relay Systems

Discussion of a paper by C. A. Muller and H. E. Turner published in the January 1936 issue, pages 56–62, and presented for oral discussion at the modernization of distribution systems session of the winter convention, New York, N. Y., January 30, 1936.

E. H. Bancker (General Electric Co., Schenectady, N. Y.): The authors of this paper have indicated how relay modernization can be carried out and what results can be accomplished from the process. Although it might be worth while to emphasize their points by reiteration, it seems more profitable to outline in this discussion when and where each of the 3 high speed, single line relay schemes should be used. These 3 schemes are: instantaneous overcurrent, stepped time distance, and carrier or wire pilot.

Improved speed of relaying is highly desirable for any of the following conditions:

1. Severe fault damage.

2. Numerous service complaints.

3. Fault duration causing too great a system disturbance.

4. Loss of synchronism.

5. Construction of extensions to existing systems.

Complete treatment of each of these points is impossible here, but it is fairly obvious from the facts pointed out by the authors that improving the speed of relaying has a beneficial effect upon all of these disturbing conditions.

Each of the 3 forms of high speed relaying has its own best field of usefulness, and it is pertinent to point out what these are.

Instantaneous overcurrent is most applicable where

1. There is a multiplicity of lines or sources of fault current.

2. The line impedance is a large proportion of the total to a fault at the far end.

3. The synchronous apparatus is relatively constant in amount.

4. Distance relays are used for phase faults, high speed ground protection is desired, and there are grounding transformers at all terminals.

5. Only a limited expenditure can be made and some improvement at several locations is more beneficial than a major improvement of a few locations.

Instantaneous overcurrent relays should have much wider use, and too much cannot be said about the major improvement they can effect in speed of fault clearing with relatively small expense. Naturally they have limitations that render them unfit for certain applications that can be better managed by 1 or other 2 methods.

Stepped distance relays find their chief use where

1. Lines run singly and there is too great a variation in short circuit current to secure effective high speed protection from instantaneous overcurrent relays.

2. There is a high percentage of twin circuit faults.

3. An entire system is to be modernized at one time.

4. Medium voltage systems are connected to properly relayed, high voltage systems, and because of long fault durations cause severe disturbances to the latter.

Distance relays similarly have their limitations, although they can be used in places where instantaneous overcurrent could not be used.

Carrier or wire pilot relaying provides the most nearly ideal system known, with practically no limitations except that the cost usually is somewhat higher than that of distance relays. It is the only form of protection that can be applied invariably with practically no regard to the existing relaying of the system. Its main field of utility is where

1. Only one line at a time can be improved, and the relaying must fit with the existing system.

2. Lines have 3 or more terminals.

3. Lines are subject to power oscillations.

4. High speed is required for all kinds of faults anywhere along the line.

5. Immediate reclosure at very high speed is desired.

6. Twin circuit faults are prevalent.

7. The lines are very short.

8. The channel may be used normally for other purposes, such as telemetering, and the cost may be divided between the 2 uses.

In comparing a wire and a carrier channel for pilot relaying, it is believed that if all of the factors are weighed carefully, the choice usually will favor carrier, except for high voltage lines of short length, on which the annual cost of the wire channel is low. No channel of communication is any stronger than its weakest link, which, in the wire system, is the wire itself. In the carrier system the reliability of the conductor attains perfection, for the conductor is used only as a channel at a time it is proving its continuity by conducting short circuit current from end to end. In the wire channel the weak link is distributed over many miles, and in case of trouble it may be difficult to determine the location and nature. With carrier equipment the only possible source of trouble lies within station yards where it is readily available for inspection and repair.

Whether the wire channel be owned by the utility or leased from a communication company, it is seldom under the jurisdiction of the same group that supervises the protective relays. In most installations of carrier for relaying the carrier equipment is maintained by relay maintenance men. The channel is, therefore, completely under the jurisdiction and supervision of the individuals responsible for the performance of the protective relaying without recourse to co-operation with other groups.

When carrier is the channel used, it is invariably employed in such a way that failure allows tripping, and when it is so used it may be turned on rapidly by means of circuit opening contacts. Wire channels also may be used in the same way to block tripping for external faults, but frequently are used more advantageously to assist in tripping. When used to block, as in carrier, circuit-closing contacts must be used to initiate the blocking, thus decreasing the relay speed. On the contrary, where a wire pilot is used for transfer tripping, or in a directional comparison scheme, it is necessary usually to employ somewhat more complicated relays or sacrifice a degree of protection, because the channel is used as a tripping medium.

Improvements in relays for carrier pilot systems have resulted in one cycle operation with a simpler and less costly equipment

than formerly used. Consequently, this best form of protection is applicable to many lines on which it might otherwise be uneconomical, with a one cycle carrier pilot system now commercially available at an attractive price.

Naturally the cheaper forms of high speed relaying have their proper sphere of application, but their lower first cost should not blind one to the many advantages of the pilot forms of protection. The freedom granted by the pilot to the system designer and operator in planning and operating systems, and the assurance that they will continue to be useful, regardless of the changes on adjacent circuit relaying, in many cases will make the extra cost insignificant in comparison with the gains derived from their use. In fact, it may be found occasionally that the availability of a relaying system such as pilot, which imposes no restrictions upon the method of operating the system, will result in a system design of less cost than could be obtained in any other way.

More and more attention is being given to the possibility of making joint use of the carrier channel for other purposes, such as telemetering and telephone, and temporarily borrowing it during system short circuits for relay purposes. This enlarged utility of the channel promises to make pilot relaying no more expensive than inferior types.

The authors of this paper have indicated the accomplishments of faster relaying. It should be remembered that whatever has been accomplished, or whatever may be accomplished, is dependent upon a careful analysis of disturbances. Accurate records are the only basis from which a true conception of events may be constructed so that the needed steps may be taken to avoid the recurrence of wrong operations in order to improve service continually. Fault clearing becomes so rapid that ordinary recording devices are practically useless, yet some record is needed to permit analysis of disturbances, especially those that appear peculiar. Thus, the adoption of any high speed relaying system greatly enhances the value of the automatic oscillograph, and the oscillograph helps to improve the performance of relaying.

B. M. Jones (Duquesne Light Co., Pittsburgh, Pa.) and **L. C. Bell** (nonmember; Duquesne Light Co., Pittsburgh, Pa.): The authors give an excellent résumé of the modernization of the relay protection on their system, and evidently they required several years to complete the improvements. However, the writers wish that some quantitative measure of the improved performance had been included.

The 6 major advantages described at the end of the paper must in the final analysis show sufficient benefits to justify the expense of the improvements. Both engineers and operators are interested in the ways and means of accomplishing these improvements, but they must be interested in results also. Furthermore they must see that the results always justify the expense.

The average clearing time of all the overheat line faults on the Duquesne Light Company system was reduced from 2.61 seconds in 1932 to 1.99 seconds in 1935, or about 62 per cent. Unfortunately, accurate records of the clearing times are not available for years prior to 1932, although a review of older records show that they were much higher. For the same period of time the per cent of total overhead faults resulting in "burn downs" was reduced from 21.4 to 4.22 per cent. A study of the overhead transmission line "burn downs" for the years 1929 to 1931, inclusive, shows that from 20.1 per cent to 23.7 per cent of the overhead faults resulted in "burn downs." It is known definitely that the size of the conductor, magnitude of the current, and the length of clearing time, have a direct bearing on the "burn downs." Weatherproof covering also has a definite adverse effect.

Faster clearing time has a direct bearing on improved service, because the rotating machinery is not "shaken off" now to the same degree it was previously. This is a material improvement in service, for the "dips" from line "break downs" cause little inconvenience now, except possibly in the immediate vicinity of the "break down" when the "dip" is very severe.

About 1926, the writers started a campaign to improve the relay performance of their system as well as associated system performance. The first obstacle was reluctance on the part of the management to appropriate the apparently large sums of money that were needed, and which were larger than any previous requests for relay protection. Early in 1927, however, a series of cases of poor relay performance was encountered, which directed the attention of the management to the problem. The necessary authorizations for test facilities and new equipment were obtained then, and the program proceeded. The results justified the expense, for the performance during that year was materially higher than for the previous year, and in subsequent years it continued to improve.

The relay performance improved from 85 per cent in 1925 to 98.1 per cent in 1935, and a most important factor is that this percentage of correct performance is based on the performance of the complete protective unit and includes relays, current transformers, potential transformers, wiring, trip coils, test terminals, breaker and mechanism, and battery. The performance of the little protective relay alone does not mean very much in itself, unless the rest of the protective unit operates properly also. Other companies may not rate their performance on this basis but it is believed to be a fairer method. The number of operations vary over quite a wide range, from 775 to 1,575, with an annual average of 1,160. These operations include the performance of the automatic oil circuit breakers on 2,300 volt, 4,000 volt, 11,000 volt, 22,000 volt, 66,000 volt systems, and on synchronous condensers, rotary converters, rectifiers, and motor-generator sets.

Some of the major factors contributing to this improved relay performance were the improvement in the speed of operation of the circuit breakers themselves, the addition of arc extinguishing contacts on existing breakers, faster trip coils and faster mechanism, together with developing better methods of checking the relay installations, changing existing relays to faster relays, adding instantaneous relays, shortening the cascaded time selection permitted by faster breaker mechanisms and arc extinguishing devices, and higher voltage batteries in small, unattended substations insuring more positive tripping. It is important that any program for widespread improvement in the relay system on a large power system must take cognizance of the large number of oil circuit breakers in service with their large investment, and although the simplest method may seem to be to throw away a great many breakers and buy new ones, this is not economically sound and probably will not be tolerated by the management. The relay engineers must get busy and develop other methods to improve the relay performance, retain the old breakers, and even modernize them at considerable expense.

In addition to the relay performance described there are other improvements, such as a reduction in the number of overhead line conductors burned down, which is due partly to the faster clearing times brought about as a result of the improved relay system and revised breakers, and due also to changes in line construction. The distribution and transmission engineers and operators claim some credit for this improvement in line performance, but the relay engineers are going to claim some of the credit, too.

Another benefit derived from the improved relay performance is a diminution of the outage time, for the faster clearing time prevents burning down the conductors; hence service can be re-established almost immediately. Many automatic reclosing attachments have been installed in conjunction with the protective schemes, and these permit quick re-establishment of service, particularly in the unattended outlying substations.

H. P. Sleeper (Public Service Electric and Gas Co., Newark, N. J.): The authors have described methods of modernizing relay systems to improve the operation of the utilities plant. They have also described methods of modernizing customer's protective equipment in order to improve continuity of service to his processes. Both of these procedures have the same ultimate object in view, namely, the improvement of the quality and the economics of the service rendered to the customer.

The authors have pointed out that the general thesis of transmission system modernization is the conversion of fault clearing equipment to high speed operation. They have quoted the principle advantages to the utility as reduced maintenance costs on transmission lines, improvement of stability of the system, and lessened voltage disturbances from faults.

There is an additional advantage, not mentioned in the paper, that may be obtained if the proper type of high speed relaying is used. This advantage is the limitation imposed by cascaded time element relaying upon the number of substations that may be connected in series on one transmission line loop. Using 0.5 second time intervals between stations, it is not permissible to connect more than 4 such stations on one single line loop, because the time setting at the source end would be excessive. This results in the long time clearing of faults that will cause excessive damage at the point of fault and give a severe dip in system voltage.

This difficulty has been removed on the Public Service system by the modernization of the 26 kv open wire transmission relay protection, which so far as short circuit pro-

tection is concerned, theoretically permits any number of substations to be connected in series. Practically this has been done by substituting high speed type *HCZ* impedance distance relays for time element directional overcurrent type *CR* relays and normal speed type *CZ* distance relays. The *HCZ* relays consist of a high speed balanced beam impedance element backed by a standard time element type *CZ* impedance element. The novelty of this relay consists of the use of a *CZ* element for back-up and end zone protection instead of the usual definite time protective element for this purpose. Another new feature of this relay is the use of a reactor in the potential circuit of the high speed element to permit the use of star connected current transformers and still obtain the maximum zones of high speed protection for all types of short circuits. This feature usually is attained by the use of delta connected current transformers; however, the mechanical complication of this connection and the consequent liability of wrong testing results by field men has caused the company just mentioned to retain star relay current connections wherever possible. As shown in figure 1 of this discussion, the reactor shifts the position of the hump in the power factor-current curve of this relay, and as a result the 30 degree difference in power factor of a 2 phase and a 3 phase fault theoretically is exactly compensated by the reverse slope of the current curve of the relay. In practice the compensation is almost entirely complete at operating voltages above 40 volts; below that value the error increases so that at 10 volts the zone covered by the instantaneous element is only 80 per cent for a 2 phase fault as compared with the 90 per cent of the length of the line covered by that element on 3 phase faults. This error is not considered to be serious, for instantaneous operation (from 1 to 6 cycles) always occurs at the nearest end.

Field tests and subsequent service faults on this modernized relaying show excellent results. Both 2 phase and 3 phase short circuits within the instantaneous zones were disconnected in from 15 to 17 cycles. It should be noted that no breaker modernization had accompanied the relay changes at that time, and the total operating time of the breakers used was a period of from 12 to 14 cycles. The use of high speed breakers would reduce the 16 cycle average fault time to about 10 cycles, possibly less. Such modernization work on these breakers now is in progress.

The service results of this relay modernization have been most satisfactory in 2 principle ways; First, the reduction of fault damage is marked. At locations where former short circuits, almost invariably caused line burning, because of the high fault energy released, only minor conductor burns now result. This obviously can be capitalized. Cases are on record in which a short circuit occurred on these 26 kv circuits, are spaced 36 inches triangularly, and an inspection after tripout failed to locate the fault because the damage was negligible.

The second result of this high speed clearing of faults has been more important than the first. Short circuits that formerly invariably resulted in customer complaints now failed to arouse even a passing comment. At first glance it seems that a period of even 15 cycles of greatly reduced voltage

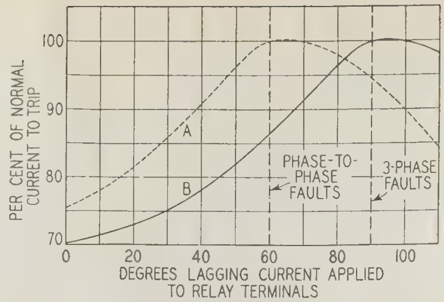


Fig. 1. Current-power factor characteristics of a type HCZ relay

A—Without reactor *B*—With reactor

would be sufficient to cause instantaneous low voltage releases to operate and disconnect motors; however, this does not seem to be the case and several theories have been advanced to explain it. The most plausible one seems to be that the voltage remote from the fault does not decay immediately, but is sustained by rotating equipment and the electrostatic capacity of the entire supply system. This is a subject for further research, but the practical result has been demonstrated satisfactorily.

The writer wishes to commend to the attention of both engineers and commercial executives, especially customer contact men, the contents of paragraph 6 on the last page of the paper. The Public Service Company has spent much time and effort during the last 7 years to educate customers to the mutual responsibility between them if maximum quality of electric service is to result. Programs similar to those advocated by the authors, and carried out by many operating utilities, will do much to minimize system disturbances and avoid service outages. Customers must modernize their motor control equipment also, so that the benefits of multiplied improvements, instead of only those proportional to the efforts of only one party to the contract, will result. It has been the writer's experience that most customers are willing to cooperate, but they are not aware of the limitation of their equipment. This lack of education of the customer usually is due to the natural result of competitive buying of equipment by nontechnical persons. This is where the utility customer contact man can do some effective work before the equipment is purchased not afterward. Teaching customers the use of motor starting devices equipped with time element overcurrent and undervoltage devices will produce satisfactory customer relations and will be most effective in contributing to the happiness of electrical operating men.

A. A. Kroneberg (Southern California Edison Co., Los Angeles): All metallic pilot wire and carrier current pilot protection schemes can be divided into 2 groups: One group will include all schemes using the signal channel for tripping, and the other group will include all schemes using the signal channel for preventing tripping. The fundamental difference between the 2 groups is that the first group depends on continuity of the signal channel for tripping a faulted line, but the second group depends on continuity of the signal channel to prevent unnecessary tripouts on through faults. The metallic wire scheme shown in figure 2 of the paper is essentially a "transferred trip" scheme and the overcurrent relays are not required for its functions. The overcurrent relays probably were added to compensate for the discrepancy in the closing and opening times of directional relays. A metallic pilot wire system of the second group is shown in figure 2 of this discussion. The blocking relay contacts are open when the relay is energized. The contacts of the directional relays are closed when power flow is from the line to the bus. A break in the pilot wire circuit will not prevent tripping, but may result in tripping of the supply end on a through fault.

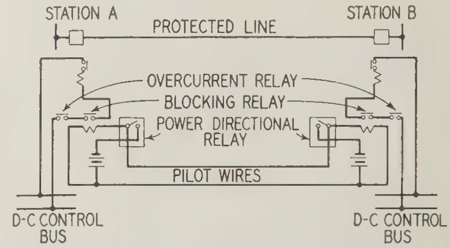


Fig. 2. A metallic pilot wire system depending on continuity of the signal channel for tripping a faulted line

Another objection to "transferred trip" relay schemes is that they cannot be applied properly to feeders and will not operate on a line energized from one end. This precludes any possibility of testing a line following a "tripout" unless some other kind of protection is available.

C. H. Frier (Oklahoma Gas and Electric Company, Oklahoma City): The problem of improving relaying of the system of the company with which the writer is connected has centered itself principally around the present directional, time delay, and overcurrent relays.

Obviously, the objective in relaying practice is to accomplish the following results with the minimum expenditure of capital investment and with the equipment most economical in maintenance and operation:

1. To maintain continuity of service over the greatest possible portion of the power system under all conditions of system operation.
2. To isolate only the line or equipment in which a fault has developed.
3. To isolate the faulted portion of the system as quickly as possible to minimize system disturbances and further to prevent overheating or severe damage due to burning of the faulted line or equipment under short circuit conditions
4. To restore service automatically as quickly as possible after a fault has been cleared.

In order to reduce the cascaded time setting of directional, time delay, and overcurrent relays, the writer has resorted to the addition of instantaneous overcurrent relays. These installations have performed satisfactorily, with a minimum of installation expense, and are easy to maintain and to operate economically.

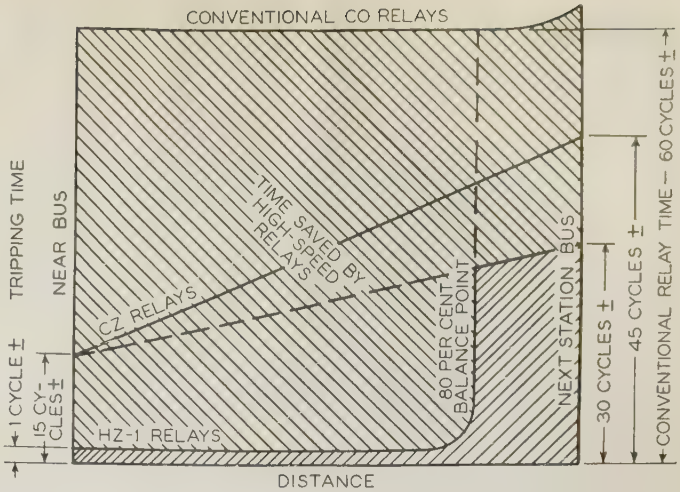
The introduction of these instantaneous overcurrent relays not only cleared a major number of disturbances in a minimum time, but also had the resultant advantage of per-

mitting a lower setting on time delay "back-up" relays. The use of these relays, however, could not be undertaken without an accurate knowledge of short circuit current values of the entire system under all generating and line operating conditions. This information was made available through the use of a permanently set d-c symmetrical component calculating board.

The use of these instantaneous overcurrent relays is being extended continually, and they are being applied to time delay bus differential relay installations. Their use has reduced high tension fuse outages materially, has relieved the system of long duration disturbances, and has reduced damage to lines and equipment to such an extent that the percentage of successful immediate reclosure of the circuits is much higher.

In considering the modernization of present relay systems, an effort has been made to strike a balance between desirability and economy, and it has been questionable whether the additional improvement to be secured by the use of the latest types of high speed relays would compensate for their cost and the retirement of the older type of relays

Fig. 3. Example of decreased operating time effected by supplementing time limit relays by high speed impedance relays



L. N. Crichton (Westinghouse Elec. and Mfg. Co., Newark, N. J.): The paper emphasizes a strange inertia in the general adoption of instantaneous overcurrent relays. The first correctly functioning directional relays were sold in 1914, and many of them were equipped with an instantaneous overcurrent attachment that would operate whenever the current was so large as to indicate trouble within that section of line. The contacts on this instantaneous attachment by-passed both the time limit current element and the directional element. Similarly, separate plunger type relays were installed at generating stations in Chicago and were set to operate at current magnitudes that would be attained when trouble was close to the station. The company with which the writer is connected produced an instantaneous plunger relay about 6 years ago, one important purpose being to supplement existing time limit relays, but its use for this duty has been disappointingly small. A few years ago this relay was improved by following the suggestions of Muller and Turner, and it is hoped that these improvements will make the device more attractive for this purpose. At present, the industry has not taken advantage of this modern relay to the extent that the authors have seen fit to do. Neither have relay engineers made the fullest use of the instantaneous attachment for the induction type relay, although it always has been available.

The need for relays of the high speed type was apparent long before the date 1930 given in the paper, and work had proceeded for several years so that high speed relays for general use on power systems were available in 1929. They were in use in railway electrification in 1928, with startling results. Those relays and many additional ones installed since that date have cleared hundreds of trolley faults without any damage to the trolley wire. When it is realized that trolley wires sometimes carry as much as 20,000 amperes at the short circuit, such performance can be fully appreciated. The relays used for that service sometimes operate in a time as short as 0.008 seconds, and the over-all operating time of the relay and breaker is less than 0.04 seconds. This is about half the most optimistic time given in the paper, and has been attained by the use of special relays and breakers. Circuit breakers used for 3-phase 60-cycle systems are not yet as fast as this, but even with the older, slower breakers there is no excuse for burning down a transmission line if high speed relays are used.

Where instantaneous overcurrent protection is desired to supplement the performance of existing induction type relays, separate plunger type relays may be installed, or the small attachment previously mentioned is available and can be mounted inside the present relay. Where a directional relay is necessary, a simple plunger element and a high speed directional element are mounted in the same case.

The high speed distance relay originally was made with one instantaneous and 2 time elements, giving a "step" type time characteristic, but now it has a competitor in the form of a relay containing one instantaneous element and one distance element with a sloping time characteristic. The basic idea of this new development is to obtain a less expensive and sturdier device. It has been developed at the suggestion of operating company engineers.

It has been proposed frequently that a simple high speed distance relay be used to protect the zone close to the switching station and use existing induction type time-limit relays to protect the far end of the line and to serve as a "back-up." This is now available in a simple relay consisting of a single high speed distance measuring element and a directional element. The time saved by this simple addition to a typical installation is illustrated in figure 3 of this discussion.

High speed differential relays now are available for protecting apparatus and bus bars. There is also a distance relay consisting of 3 instantaneous elements, one for each phase, and intended to be used for the protection of busses that are sectionalized by reactors. No directional or time elements are necessary, and the apparatus is simple, because the reactors definitely locate the trouble. This relay has been used in several cases because of its comparatively simple connections. The differential relay will, of course, operate on any bus, but it sometimes requires many interconnections between current transformers.

Of the 6 specific advantages of high speed relaying mentioned by the authors, it seems that the most timely one is the possibility of obtaining improved stability even when transmitting greater amounts of power over existing systems.

New Lamp Produces Germicidal Rays

A new low-wattage gaseous-conductor lamp that produces radiation germicidal to mold spores in the air was announced recently by the Westinghouse Lamp Company, Bloomfield, N. J. The lamp is a slender gas tube containing a small quantity of a special gas. Experimental tests and several practical applications of these lamps are said to have established definitely the effectiveness of the germicidal rays for preventing the growth of mold and bacteria on the surface of meat aged at relatively high temperature and high humidity, and in retarding the growth of mold on bakery products. The radiation also is said to repulse several types of insects and to exert a lethal effect on other insects which it attracts. The accompanying illustration shows Dr. Harvey C. Rentschler and Dr. Robert F. James, developer of the lamp, examining one of the devices.

News
Of Institute and Related Activities

52d Annual Summer Convention Successfully Held at Pasadena, Calif.

ALTHOUGH the Institute previously had held summer conventions as far west as Denver, Colorado (1928) and Salt Lake City, Utah (1921) the Fifty-Second Annual Summer Convention, held June 22–26, 1936, at the Huntington Hotel at Pasadena, California, was the first to be held on the Pacific Coast. Judging by the full and widely representative attendance, by the active participation in technical and social affairs, and by the comments overheard in lobbies and meeting halls, the convention was unquestionably a success in every department and a credit to all who planned and conducted its several activities. Organized under the leadership of former Vice President R. W. Sorensen, and directly sponsored by the Los Angeles Section, the convention was actively supported by the other Pacific Coast Sections at San Francisco, Portland, Seattle, Vancouver, Spokane, and Salt Lake City. Inspired by the Pasadena success, the San Francisco Section has launched an effort to obtain the 1939 summer convention for San Francisco in connection with the Exposition with which San Francisco expects to celebrate the completion of its 2 record breaking bridges, the Trans-Bay Bridge and the Golden Gate span.

For the benefit of those who did not attend the convention, and as a reminder and a record for those who did, a comprehensive news digest covering the highlights of convention activities is presented on this and following pages.

Annual Business Meeting

A heavy attendance featured the opening session of the convention, which was held Monday morning June 22 in the Grand Ballroom of the Huntington Hotel with President Meyer presiding. City Manager C. W. Koiner (A'04, F'12) delivered on behalf of the City of Pasadena a message of generous welcome to the Institute and its guests, to which Professor Sorensen responded on behalf of the Institute.

Reports of the Board of Directors and the Committee of Tellers

National Secretary H. H. Henline presented a digest of the report of the board of directors for the fiscal year ending April 30, 1936, explaining that this annual report is really a large number of brief reports covering practically all phases of the Institute's activities and many joint activities in which this Institute co-operates with other organizations. One of the outstanding features of the year reported was the generous expenditure of time and effort on the part of President E. B. Meyer in visiting during the year some 26 Sections and nearly as many educational institutions and student Branches.

Concerning general activities, Mr. Henline reported that the Institute had held the usual 3 national conventions during the year and that all were well attended; also that the Sections had an outstanding year, reporting 540 meetings, the largest total ever reported. There was a marked increase in the holding of special meetings of several types especially designed to afford to individuals in the various fields opportunities for personal participation. He reported also that Branches had enjoyed one of the most successful in recent years with a total of 1,045 meetings, the largest since 1932.

President E. B. Meyer (left) and President-Elect A. M. MacCutcheon both took active parts in the convention program

(The current annual report of the board of directors was published in full in the July 1936 issue of Electrical Engineering beginning on page 795, and contains information that should be of interest and value to every member interested in the affairs of his Institute.)

The report of the committee of tellers also was published in the July issue, on page 838.

Treasurer's Report

National Treasurer W. I. Slichter, professor of electrical engineering, Columbia University, New York, N. Y., reported a separate and personal verification of Institute accounts as covered in the auditor's statement published as a part of the report of the board of directors. He expressed pleasure in also being able to report that in spite of increased Institute activity during the past year, it has been possible to pay back a large proportion of the withdrawals from the reserve capital fund that were required to carry through 1932, 1933, and 1934. Professor Slichter reported further: "On the investment side we have had a great deal of worry. . . . . of course, the price and the market value of our securities went way down and then, as things began to get better, the various companies began to call their bonds and replace them with bonds having a lower income. Our finance committee has watched this carefully and suggested to the Board, and the Board approved the suggestion, that we secure professional counsel. With the help of this investment counsel, which . . . . . is strictly advisory and does not do any buying or selling, we have managed to put our principal in such a condition that now at market prices its value is in the neighborhood of 90 per cent of the actual cost price . . . . . We, therefore, can feel that our finance committee and our board of directors have managed our finances very well and that we can be very hopeful of the future."

Prize Awards

Immediately following the reading of the report of the national committee on award of Institute prizes by R. N. Conwell, a member of that committee, the awards were presented by President Meyer to the recipients present. The Committee's report was published beginning on page 754 of Electrical Engineering for June 1936, and additional District awards are listed on page 839 of the July issue.

Lamme Medal for 1935 Presented to Dr. Bush

Dr. Vannevar Bush (A'15, F'24) vice-president and dean of engineering of Massachusetts Institute of Technology, received during the annual convention business session at Pasadena the eighth in the series of the Institute's Lamme Gold Medals "for his development of methods and devices for application of mathematical analysis to problems of electrical engineering."

Other Lamme Medal Awards

Previous awards of the A.I.E.E. Lamme Medal have been made as follows:

1928—To A. B. Field (A'03, F'13) of Manchester, England

1929—To R. E. Hellmund (A'05, F'13) of E. Pittsburgh, Pa.

1930—To W. J. Foster (A'07, F'16) of Schenectady, N. Y.

1931—To Giuseppe Faccioli (A'04, F'12) *deceased*, of Pittsfield, Mass.

1932—To Edward Weston (M'84, HM'33, member for life, past-president) of Newark, N. J.

1933—To L. B. Stillwell (A'92, F'12, member for life, past-president) of Princeton, N. J.

1934—To H. E. Warren (A'02) of Ashland, Mass.

The Institute's Lamme Medal was established by provision of the will of Benjamin Garver Lamme (deceased July 8, 1924) for the encouragement and recognition of "meritorious achievement in the development of electrical apparatus or machinery." Similar bequests were made to Ohio State University and to the Society for the Promotion of Engineering Education. The Lamme Medal of the Ohio State University is awarded to a graduate of one of the technical departments of that school for meritorious achievement in engineering or the technical arts; for 1935 was presented to E. G. Bailey of New York, N. Y., '03 graduate in mechanical engineering and now president of the Bailey Meter Co. of Cleveland, O., president of the Fuller-Lehigh Co., of Allentown, Pa., and vice president of the Babcock & Wilcox Co., of New York, N. Y. The ninth Lamme Medal award of the SPEE was made to Dean Herman Schneider, president emeritus of the University of Cincinnati, Ohio, and founder of the co-operative plan of education at that school in 1906.

Timbie Introduces Medalist Bush

Having difficulty in suppressing his spontaneous enthusiasm to extol the attributes of medalist Bush as a sportsman, sailor, and humanitarian in addition to his more widely known prowess as a teacher, inventor, lecturer, and administrator, Professor W. H. Timbie sketched the highlights of Dr. Bush's technical career:

"Dr. Vannevar Bush is noted for his achievements in electrical research and contributions to technical education . . . a native of Everett, Mass., son of the late Rev. R. Perry Bush, for 50 years a clergyman in the vicinity of Boston . . . has long been interested in the design of analyzing instruments and is internationally known for his achievements in this field . . . recently lectured at Cambridge, England, at the International Congress of Applied Mechanics on instrumental analysis, and delivered the Josiah Willard Gibbs lecture of the American Mathematical Society on another aspect of the subject. One intricate calculating machine, the differential analyzer, developed at the Massachusetts Institute of Technology under his direction, is capable of solving complex ordinary differential equations, and hence greatly increases the possible range of engineering calculations.

"With the co-operation of Dr. Bush and other members of the (MIT) staff, several models of the differential analyzer have been built in various parts of the world . . . .

"Dr. Bush directed the design and construction at Technology of the network analyzer, a device for accurately reproducing and studying the operating characteristics of power networks under the most satisfactory conditions. He has also carried out important studies of transients in machines and in interconnected power systems, and is known for his contributions to the development of thermionic and gaseous conduction tubes. He was active for many years in the introduction of operational methods of circuit analysis to engineering problems, and was one of the group of pioneers in the application of this powerful mathematical method of analyzing transients.

"Dr. Bush was invited to join the faculty of the Institute in 1919 to undertake a comprehensive study of the undergraduate curriculum in electrical engineering and to develop the most efficient methods of teaching in this field. He also has been professor of electrical power transmission, and his career as a teacher has been no less notable than his achievements in research. His appointment as vice president and dean of the school of engineering of MIT was announced on March 10, 1932. At the same time he was elected a member of the MIT corporation. . . ."

Lamme Medalist Vannevar Bush (left) of Cambridge, Mass., in conversation with E. A. Crellin, past-chairman of the San Francisco Section

Dr. Bush Responds

In responding to Professor Timbie's address, Dr. Bush stated: "I can best express my appreciation of the honor conferred upon me in the presentation of this medal by expressing my appreciation of the qualities of Benjamin Garver Lamme who founded it. Lamme was an engineer, and therefore, one who applied science in an economic manner for the benefit of mankind. He was an outstanding engineer because of the effective way in which the important attributes of the profession of engineering were blended in his character. . . . The American Institute of Electrical Engineers does well, by this ceremony of a medal, to perpetuate the name and memory of a great engineer. I am happy to have a part in such an affair. . . ."

The text of Dr. Bush's address is published on page 854 of this issue.

Other Features of the Program

Conference on Local Student Affairs

Student chairmen and counselors from student Branches throughout the 8th and 9th Districts met Tuesday afternoon, June 23, under the chairmanship of E. F. Peterson of Santa Clara (Calif.) University, to discuss affairs of particular interest to student Branches throughout the Pacific Coast territory, and to discuss plans and projects for the coming year. Particular attention was given to the several phases of the problem of developing good student papers, with particular reference to the expected beneficial effects of the allowance of a separate prize award for papers prepared by graduate students, and of changes already made in the prize rules governing student papers or recommended to be made (see report of Pasadena conference of officers, delegates, and members, page 929).

A discussion concerning the desirability of maintaining a check on the submission of reports to the national secretary concerning Branch activities revealed the general consensus of opinion to the effect that "each counselor could and should keep informed regarding such reports" as made by Branch secretaries.

A general discussion of the desirability of preparing a "Manual of the Duties of Counselors" revealed a consensus of opinion that such a manual would be a helpful guide to counselors, and led to the appointment of a committee, comprising all student counselors for Districts 8 and 9, charged with the responsibility "to prepare a list of suggested duties and activities of counselors."

The meeting was addressed briefly by National Secretary Henline, Vice Presidents McMillan and Hinson, Vice President-Elect C. E. Rogers, and Chairman O. W. Eshbach of the national committee on student Branches.

Table II—Summer Convention Attendance During Recent Years

1936	Pasadena, Calif.	*(8)	715
1935	Ithaca, N. Y.	(1)	904
1934	Hot Springs, Va.	(4)	351
1933	Chicago, Ill.	(5)	968
1932	Cleveland, Ohio	(2)	1,022
1931	Asheville, N. C.	(4)	525
1930	Toronto, Ont., Canada	(10)	1,110
1929	Swampscott, Mass.	(1)	1,000
1928	Denver, Colo.	(6)	500
1927	Detroit, Mich.	(5)	1,200
1926	White Sulphur Spgs., W. Va.	(2)	350
1925	Saratoga Spgs., N. Y.	(1)	900
1924	Chicago, Ill.	(5)	750
1923	Swampscott, Mass.	(1)	1,616
1922	Niagara Falls, N. Y.	(1)	950
1921	Salt Lake City, Utah	(9)	426
1920	White Sulphur Spgs., W. Va.	(2)	314

* District numbers in parentheses.

Technical Sessions

Heavier than ordinary for a summer convention, the technical program of 10 sessions

Table I—Analysis of Attendance at 1936 Summer Convention, Pasadena, Calif.

Classification	Dist. 1	Dist. 2	Dist. 3	Dist. 4	Dist. 5	Dist. 6	Dist. 7	Dist. 8	Dist. 9	Dist. 10	Foreign	Totals
Members	23	38	30	11	26	5	17	270	40	2	2	466
Men guests	3	8	2	2	5		3	30	2			54
Women guests	23	32	24	9	15		12	63	18			195
Totals	49	78	56	22	46	5	32	363	60	2	2	715

at Pasadena provided for the presentation and the discussion of some 48 formal technical papers, supplemented by some impromptu discussions and by 6 informal technical conferences: high voltage X-ray tubes and allied apparatus, carrier currents, mechanical properties of electrical conductors, synchronous machines, general transformer problems, and electron tubes in industry, all in accordance with the program as published beginning on page 554 of the May 1936 issue of ELECTRICAL ENGINEERING and amended on pages 747–8 of the June issue.

ATTENDANCE

In spite of early misgivings, the final official total of those actually registered at Pasadena amounted to 715. Analysis of the attendance figures as included in the 2 accompanying tabulations, and the comparison of these with similar figures published in previous years discloses interesting facts.

ENTERTAINMENT

The convention entertainment program began Monday evening with the president's reception and informal dance held at the Huntington Hotel, and included among its features a dance and elaborate variety show Tuesday evening, a heavily attended excursion to the 6,000-foot summit of nearby Mount Wilson where members and guests enjoyed a picnic box supper and an inspection of the famous astronomical observatory as well as a view of the lights of the many valley towns and cities after dark. Thursday evening, convention delegates and guests were entertained in the Pasadena Municipal Auditorium by a concert of the famous Tournament of Roses Band followed by an illustrated lecture concerning the "technicolor" process of producing naturally colored pictures of high quality. The grand finale of the general entertainment program came Friday evening when delegates and guests assembled on the terraces surrounding the swimming pool on the Huntington Hotel grounds to enjoy an outdoor buffet supper and to witness the presentation of the several sports prizes. Entertainment features especially planned for the women included a lawn party and musicale Monday afternoon, a 120 mile tour of Hollywood and nearby beaches all day Tuesday, a sight-seeing trip through nearby foothill country Thursday, and a bridge party Friday afternoon.

Honors in the women's sporting events were won as follows: Putting, Mrs. G. G. Post, Milwaukee, Wisconsin; novice putting, Mrs. L. A. Nott, San Francisco, California; swimming, Miss Eloise Ferris, Upper Montclair, New Jersey; tennis, Mrs. F. J. Groat, Brooklyn, New York; ping-pong, Miss Jane Dawes, Cambridge, Mass.

Honors in the men's swimming race were captured by Robert Schnure of Sparrows Point, Maryland; and, in the diving contest, by L. P. Ferris II of Upper Montclair, N. J.

C. E. Johnson
Mershon Golf Trophy

Among Summer Convention Sports Winners

GOLF

Inasmuch as the usual annual Pacific Coast convention was combined with the summer convention at Pasadena, there was a triumvirate of major prizes involved: the Mershon Trophy, open for national competition among Institute members on the basis of a match play under handicap; the W. S. Lee Trophy, open for national competition among Institute members, awarded for the lowest net score for 36 holes; the John B. Fisken Cup, open for competition only among A.I.E.E. Pacific Coast members in good standing, awarded for the lowest net score for 18 holes.

In a field of stiff competition, winners in the Mershon tournament were:

Winner—C. E. Johnson (A'09, F'25) of Los Angeles, Calif.

Runner-up—R. F. Gheen (A'25) of Los Angeles, Calif.

Mr. Johnson will be the first to have his name engraved on the present trophy which is the third cup donated by Past-President Ralph Mershon, the first having been won in 1931 by L. F. Deming of Philadelphia, Pa., after having withstood competition since 1912; the second having been won in 1935 during the summer convention at Ithaca, N. Y., by L. R. Keiffer of Cleveland, Ohio, after having been in competition for only 4 years. The regulations covering the present trophy are that it shall remain on permanent exhibit at A.I.E.E. headquarters in New York, N. Y., bearing engraved upon it the name of the winner of each successive year's competition.

The Lee golf trophy, presented in 1932 by the late Past-President W. S. Lee, must be won twice by the same player for permanent possession. The results of the 36 hole medal play at Pasadena were:

Winner—H. S. Warren (A'35) of Los Angeles, Calif.

Runner-up—R. A. Monroe of Denver, Colo.

Thus, names now appearing on the Lee trophy are:

1932—C. H. Teskey, Cleveland, O.
1933—G. R. Canning, Cleveland, O.
1934—F. M. Craft, Atlanta, Ga.
1935—A. H. Sweetnam, Boston, Mass.
1936—H. S. Warren, Los Angeles, Calif.

District team competition on the basis of 36 hole medal play was entered into by 2 composite teams, one representing the West and one representing the East. The Western team won as follows: E. W. Rockwell of Los Angeles, Calif., 160; J. C. Henkle of Portland, Oregon, 167; H. S. Warren of Los Angeles, Calif., 169; H. D. Hawks of Los Angeles, Calif., 174; total 670.

Winners in the Pacific Coast cup competition were:

Winner—J. C. Henkle (A'19, M'20) of Portland, Ore., 70.

Runner-up—E. R. Northmore (A'07, F'28) of Los Angeles, Calif., 71.

Future AIEE Meetings

South West District Meeting
Dallas, Texas, Oct. 26–28, 1936

Southern District Meeting
Birmingham, Ala., Dec. 1936

Winter Convention
New York, N. Y., Jan. 25–29, 1937

North Eastern District Meeting
Buffalo, N. Y., May 1937

Summer Convention
Milwaukee, Wis., June 21–25, 1937

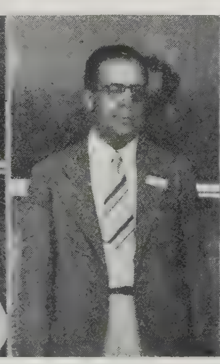
Pacific Coast Convention
Spokane, Wash., Date to be determined

Middle Eastern District Meeting
Akron, Ohio, Fall 1937

Miss Jane Dawes
Ping Pong

Miss Eloise Ferris
Swimming

Mrs. L. A. Nott
Novice Putting



H. S. Warren
W. S. Lee Golf Trophy

J. C. Henkle
John B. Fisken Cup

E. F. Lopez
Mershon Tennis Trophy

Named in honor of John B. Fisken, hydro-electric pioneer of the Pacific Northwest, the Fisken cup was donated originally by the Portland Section. After 16 annual competitions, names appearing on the Fisken trophy are:

1920—C. L. Wernicke, Portland, Ore.
1921—C. P. Osborne, Portland, Ore.
1922—J. B. Fisken, Spokane, Wash.
1923—S. J. Lisberger, San Francisco, Calif.
1924—K. E. Van Kuran, Los Angeles, Calif.
1925—W. C. Heston, San Francisco, Calif.
1926—P. M. Downing, San Francisco, Calif.
1927—C. E. Heath, Los Angeles, Calif.
1928—G. D. Luther, Seattle, Wash.
1929—E. W. Rockwell, Los Angeles, Calif.
1930—W. F. Hynes, Portland, Ore.
1931—M. S. Barnes, San Francisco, Calif.
1932—J. E. Underhill, Vancouver, B. C., Canada.
1933—No convention.
1934—H. W. Flye, San Francisco, Calif.
1935—H. H. Schoolfield, Portland, Ore.
1936—J. C. Henkle, Portland, Ore.

Blind bogey winners for the 3 days of play included:

M. S. Barnes, San Francisco, Calif; A. D. Bragg, Fresno, Calif; F. H. Cole, Los Angeles, Calif.; E. H. Dinwiddie, Oklahoma City, Okla.; F. R. George, San Francisco, Calif.; and H. D. Hawks, Los Angeles, Calif.

Tennis

Principal event on the popular tennis schedule was the annual tournament competition for the Mershon trophy. Following several hotly contested elimination matches, E. F. Lopez, delegate from Mexico City, and T. M. Blakeslee of Los Angeles, Calif., came into the final match which was won by Lopez 6–2, 6–0, 6–2. Thus, delegate Lopez added to his string of Institute tennis laurels by winning the right to be the second to have his name engraved upon the new Mershon trophy. At the Summer Convention in Hot Springs, Va., in 1934 delegate Lopez for the second time won the original Mershon tennis trophy, thereby securing permanent possession of it after it had been under competition 8 times. In 1935 Past-President Ralph Mershon donated to the Institute a new tennis trophy with the stipulation that it should remain on permanent exhibit at Institute headquarters with the names of the successive winners engraved upon it. The first to have his name so engraved was Allen O. White, Washington, D. C., who won the tournament at Ithaca in 1935.

Annual Conference of Officers, Delegates, and Members Held at Pasadena, Calif.

Under the joint sponsorship of the Sections committee and the committee on student Branches, the annual conference of officers, delegates, and members of the Institute assembled Monday and Tuesday afternoons June 22 and 23, 1936, in the ballroom of the Huntington Hotel, Pasadena, Calif., as a part of the summer convention activities. In addition to other interested persons, delegates from 58 Institute Sections and the counselor-delegates from all of the 9 Districts in which committees on Student activities have been organized, were present. A list of these is given in the accompanying tabulation. The total recorded attendance was 106.

Principal topics discussed were essentially as outlined in a program previously mailed to the delegates and others:

Monday, June 22, 2:00 p.m.

Joint General Session—I. Melville Stein, Chairman, presiding.

1. Opening of conference; announcements by I. Melville Stein, chairman of the Sections committee.

2. Remarks by E. B. Meyer, president.

3. Functions and Results of Conferences of Officers, Delegates, and Members—H. H. Henline, national secretary.

4. Institute Finances—L. W. W. Morrow, representing finance committee.

5. Membership Activities—Everett S. Lee, chairman national membership committee.

Monday, June 22, 3:30 p.m.

Session A—Sections Committee Meeting—I. Melville Stein, Chairman, presiding.

6. Section technical activities—

(*a*). Report of results from questionnaires—I. Melville Stein.

(*b*). Technical Activities of the New York Section—F. P. West, chairman power group, New York Section.

(*c*). Technical Activities of the San Francisco Section—E. M. Wright, chairman San Francisco Section.

(*d*). General Discussion.

Session B—Student Branches Committee Meeting—O. W. Eshbach, Chairman, Presiding.

Consideration of matters of special importance in connection with Student activities

Tuesday, June 23, 2:00 p.m.

Session C—Resumption of Joint Session

7. Report of meeting of committee on student Branches, including recommendations for consideration of the joint group—O. W. Eshbach, chairman committee on student Branches.

8. Résumé of Monday afternoon's Sections session—I. Melville Stein.

9.

(*a*). Methods by Which a Section May Arouse and Retain the Interest of More Members—E. T. Mahood, chairman Kansas City Section.

(*b*). Section Educational Courses—W. B. Morton, Philadelphia Section.

(*c*). Co-operation of Sections With Local Civic and Public Welfare Organizations—H. M. Witherow, chairman Fort Wayne Section.

(*d*). Résumé of Miscellaneous Suggestions Received From Sections—W. A. Sumner, chairman Sharon Section.

(*e*). General Discussion.

10. The Coming Year—A. M. MacCutcheon, President-Elect.

Inasmuch as the annual report of Section and Branch activities was published in full beginning on page 752 of the June 1936 issue of Electrical Engineering and thus circulated to the entire membership, no pamphlet copies of the report were prepared for use at the conference, and nothing further remains to be reported here.

Opening Session

Following brief introductory remarks by Chairman I. Melville Stein, President E. B. Meyer spoke briefly in appreciation of the cordial treatment accorded to him upon the occasion of his many visits to Institute Sections and Branches during the past year: . . . "I think that one of the best things that has come to me as the result of all these visits was the opportunity of meeting so many of you delegates. I have had many opportunities to speak with the men in the various sections of the country, and it has been a pleasure to meet them and to see the wonderful meetings that are being held. I was surprised that so few had any comments to make. There seems to be a feeling of satisfaction with the Organization. . ."

Reports of National Secretary and Finance Committee

Reporting upon the disposition of resolutions passed at the 1935 conference, sketching the history of these conferences and pointing out their significance and importance in the conduct of Institute affairs, National Secretary Henline spoke briefly:

"Several recommendations were made at the conference held a year ago . . . further consideration has been given them, and certain action has been taken.

"One . . . had to do with the re-establishment of the office of Assistant National Secretary. After receiving a report from the committee on student Branches, the board of directors gave this matter further consideration during the year. The final decision was that this recommendation is not necessary at this time; that the work of the Branches is being adequately carried on.

". . . a recommendation . . . that articles especially for students be prepared for publication in Electrical Engineering . . . was referred to the publication committee, which agreed . . . the committee on education appointed a subcommittee to prepare papers . . . the board of directors approved the report. . . .

"As a result of the discussion at the 1935 conference, Chairman Stein issued a questionnaire to the membership concerning the technical activities in Districts and Sections of the Institute. A report on that will appear later. (See page 930.)

". . . a recommendation that any Section holding at least 6 technical meetings during the year would not be required to return its unexpended balance at the end of the year . . . (and) that the traveling expenses allowed be 10 cents per mile one way . . . were referred to the finance committee, but that committee could not see its way clear to recommend adoption. . . .

"The 1935 conference recommended that the Institute encourage competitions conducted by the Sections, encourage the younger members to take part in their activities . . . issue a certificate . . . and give national recognition to the competitors. This was endorsed by the committee on award of Institute prizes, with the suggestion that certificate be awarded through the Sections to the individuals. The board accepted this report."

A partial view of one of the officers, delegates, and members conference sessions

Speaking briefly of the history and the significance of these annual conferences, National Secretary Henline called specific attention to the fact that "For several years they have been known as 'conferences of officers, delegates, and members' to indicate definitely that all members are at liberty to attend and to take part in the discussion." He pointed out that these meetings have been devoted to discussion "of a great many subjects, and more especially any subject of interest to the Sections or the Institute as a whole" and that many important Institute policies have been developed through the conferences. Growing out of the meetings of the Sections' committee, these conferences were, from 1911 to 1921 held at various times during the summer convention, and without a very definite plan. Since 1921 the conferences have been held as a part of the regular program of the annual summer convention, and since 1927 the committee on student Branches and others interested in that phase of Institute activities have joined in the conference activities. These conferences were characterized by Mr. Henline as being "the most widely representative (Institute) group that meets during the year."

L. W. W. Morrow, reporting briefly for Chairman R. H. Tapscott of the finance committee referred to the fiscal statement contained in the board of directors' report published beginning on page 795 of the June 1936 issue of Electrical Engineering, and outlined the efforts of the finance committee to maintain Institute activities on the basis of a balanced budget. Referring to the current budget of $260,000 for the year ending September 30, Mr. Morrow reported receipts for 9 months at 77 per cent of the estimated total income, and expenditures at 73 per cent of the estimated requirements.

Membership Committee Report

In reporting upon the results of the third year of membership committee activities to be conducted under his national chairmanship, Everett S. Lee of Schenectady, N. Y., stated that "This year I come with convictions which have grown more firm as I have seen the results of the Membership activities during this time. I entered the work secure in the feeling that our Institute was fundamently sound; that it represented the best; that it had made the profession . . . and today I see the same picture augmented by the results of all of us who have contributed as we have been able. To me the Sections are the Institute, and . . . the Section . . . officers hold the key to the success of our venture. The members of the Institute will largely feel its active pulse as your Section covers the range of abilities of your Section membership."

As examples of effective broadening of Section activities, Chairman Lee cited the successful activities of the New York, Chicago, Pittsfield, Schenectady, San Francisco, Portland, Boston, Lynn, Niagara Frontier, Philadelphia, Cleveland, Sharon, Seattle, and Toledo Sections, items concerning most of which have appeared in Electrical Engineering from time to time.

The inspiring text of Chairman Lee's address and report is scheduled for publication in the September issue.

Revision of Section Territories

Taking up briefly a non-programmed subject Chairman Stein called upon Secretary Henline to read a progress report made to the board of directors under date of May 20, 1936. The gist of this report from Chairman Stein was that complete reports had been received from Districts 4, 5, 6, and 8; that Districts 1 and 2 were at work on the problem; that probably no report was to be expected from District 3; that early reports were expected from Districts 7 and 9; and that the situation in District 10 (Canada) was in the hands of the vice president from that district; that "it seems probable that the committee will be able to submit a complete report to the August (1936) meeting of the board of directors. . . ."

Section Technical Activities

Since the 1934 conference held during the summer convention at Hot Springs, Va., the general subject of Section and District technical activities has been actively under discussion and consideration in many Institute circles. Reflecting suggestions that had been made, and to afford some definite basis for discussion, a statement entitled "Technical Committee Activities Proposed for Sections and Districts" was prepared by Chairman Stein and published on page 631 of the April 1934 issue of Electrical Engineering. As a result of the discussion of the subject at the Hot Spring conference in June 1934, a resolution was passed recommending to the board of directors "that such changes be made in the by-laws of the Institute as will provide for an expansion in function and membership of the national technical committees and for the creation of District and Section technical committees," and suggesting in some detail the manner in which the proposed results might be realized. This resolution was considered by the board of directors June 27, 1934, and referred to the technical program committee for study and report. (See Electrical Engineering, Aug. 1934, p. 1232). During the ensuing year the subject was considered further by the several interested committees, and also came up for further discussion at the 1935 conference held in connection with the summer convention at Ithaca, N. Y. (See Electrical Engineering, Aug. 1935, page 900.)

During the administrative year 1935–36, the Sections committee, after having given the subject still further consideration, caused a questionnaire to be sent to all active members in good standing in Section territory and to some in non-Section territory. Concerning the returns from the 8,700 questionnaires, Chairman Stein reported as follows:

"Replies were received from approximately 2,400 members in Section territory, or from about 28 per cent of those to whom the circular was sent. Of that approximately 2,400 replies, 1,843 voted in favor of the proposed plan, and of this number 1,757 said they would participate in the activities in section technical committees if such were established. 423 were opposed to the plan, and of this number 411 stated they would *not* participate in Section technical activities if such were formed.

Membership—

Mr. Institute Member:

This is the last membership message from the present committee and we all want to thank you for your splendid co-operation which has made the membership advances of the past few years possible.

This is a continuing work which never ends, and you will therefore undoubtedly be asked by the new membership committee for your continued helpfulness.

July 10, 1936

Chairman, National Membership Committee

"On the basis of membership grades, it is interesting to note that Fellows and Members were somewhat more responsive than Associates. With reference to those voting in favor of the plan, we received replies from approximately 17 per cent of the Fellows and 18 per cent of the Members against approximately 11 per cent of the Associates. Likewise, in connection with those opposing the plan the responses came from approximately 8 per cent of the Fellows, 5 per cent of Members, and 1.5 per cent of the Associates. The replies indicate no difference in sentiment with relation to geographic location of the sections nor with reference to the size of Sections. Fornstance, in the New York Section, where group meetings have been held for some time, the circular was sent to an active membership of 2,773 and replies were received from 479. Of these, 410 voted in favor of the plan and 78 against it . . . In general the comments show that those who were opposed to the plan were looking at the matter almost entirely from the point of view of the national technical committee. They seemed to feel that that committee did not need that kind of a setup.

"The only general conclusion we can draw from the questionnaire is that those who voted on it, about 2,400 out of 8,700, were definitely in favor of . . . greater technical activities throughout the sections . . . no matter what particular form of arrangement is carried out. . .

"I wish to call attention to the opening sentence in our by-law (Sec. 85) which prescribes the duties of the national technical committees and that reads as follows: "The technical committees shall promote and co-ordinate Institute activities in their respective fields." Perhaps this whole

Table I—Record of Attendance of Section Delegates and Student Branch Counselors at Pasadena Conference

Section	Delegate Name and Affiliation
Akron	V. W. Shear (A'06, M'12) owner, Verne W. Shear and Co.; Section chairman 1935–6
Alabama	H. J. Sholz (A'21) engineer, Commonwealth and Southern Corp., Section chairman 1934–5
Atlanta	T. W. Fitzgerald (A'15, M'21) professor and head of department of electrical engineering, Georgia School of Technology; student Branch counselor
Baltimore	F. O. Schnure (A'23, M'35) electric superintendent, Bethlehem Steel Co.; Section chairman 1935–6
Boston	C. L. Dawes (A'12, F'35) associate professor of electrical engineering, graduate school of engineering, Harvard University; Section chairman 1936–7
Central Indiana	D. T. Canfield (A'22, M'31) associate professor of electrical engineering, Purdue University; Section vice-chairman, 1935–6
Chicago	Burke Smith (A'17, M'28) Transmission Engineer, Illinois Bell Telephone Co.; Section chairman 1936–7
Cincinnati	A. C. Burroway (A'25) division plant supervisor, Cincinnati and Suburban Bell Telephone Co.; Section chairman 1936–7
Cleveland	W. E. Wickenden (A'07, M'13) president, Case School of Applied Science; Section chairman 1936–7
Columbus	E. E. Kimberly (A'34) associate professor of electrical engineering, Ohio State University; Section chairman 1936–7
Connecticut	R. H. Van Horn (A'22) manager, United Illuminating Co.; Section chairman 1935–6
Dallas	O. S. Hockaday (A'20, M'28) superintendent of transmission, Texas Electric Service Co.
Denver	W. L. Cassell (A'25) associate professor of electrical engineering, University of Colorado; Section chairman 1935–6
Detroit-Ann Arbor	H. P. Seelye (A'19, M'28) engineer, Detroit Edison Co.; Section chairman 1935–6
Erie	W. H. Reynolds (A'04, M'26) retired, General Electric Co.; Section chairman 1935–6
Florida	Joseph Weil (A'24, M'31) head of electrical engineering department, University of Florida; Section secretary, 1936–7
Fort Wayne	H. M. Witherow (A'28) designing engineer, General Electric Co.; Section chairman 1935–6
Houston	M. C. Hughes (A'20, M'32) head of electrical engineering department, Agricultural and Mechanical College of Texas; Section chairman 1936–7
Iowa	E. B. Kurtz (A'20, F'29) professor and head, electrical engineering department, University of Iowa; Section chairman 1935–6
Ithaca	B. K. Northrop (A'22) professor of electrical engineering, Cornell University; Section chairman 1935–6
Kansas City	E. T. Mahood (A'26, M'28) engineer, Southwestern Bell Telephone Co.; Section chairman 1935–6
Lehigh Valley	S. S. Seyfert (A'05, M'13) professor of electrical engineering, head of department and director of curriculum, Lehigh University; Section vice-chairman, 1935–6
Los Angeles	O. W. Holden (A'23, M'34) junior electrical engineer, Bureau of Power and Light, City of Los Angeles; Section chairman 1935–6
Louisville	G. M. Miller, Jr. (A'21, M'26) superintendent, electrical distribution and construction, Louisville Gas and Electric Co.; Section chairman 1935–6
Lynn	T. A. Abbott (A'26, M'31) superintendent, meter department, General Electric Co.; Section chairman 1936–7
Madison	R. R. Benedict (A'27) instructor in electrical engineering, University of Wisconsin; Section chairman 1936–7
Memphis	W. H. Rollman (A'31) relay department, Memphis Power and Light Co.
Mexico	E. F. Lopez (A'16, M'18) special representative, Thomas A. Edison, Inc., International Division; Section chairman, 1925–6, 1931–2
Milwaukee	J. F. H. Douglas (A'20, M'35) associate professor of electrical engineering, Marquette University; Section chairman 1935–6
Minnesota	J. H. Kuhlmann (A'18, M'27) associate professor of electrical design, University of Minnesota, student Branch counselor
Montana	W. A. Boyer (A'26) electrical engineer, Anaconda Copper Mining Co.; Section chairman 1935–6
Nebraska	C. E. Winn (A'17) division plant engineer, Western Union Telegraph Co.; Section chairman 1935–6
New Orleans	C. W. Ricker (A'18, M'36) professor of electrical engineering, Tulane University; Section chairman 1935–6
New York	F. P. West (A'25) assistant engineer, The New York Edison Co., Inc.; chairman Section power group 1935–6
Niagara Frontier	J. L. Scanlon (A'28, M'34) general manager, J. Leo Scanlon Co.; Section chairman 1936–7
No. Carolina	
Oklahoma City	E. H. Dinwiddie (A'29) inventory and costs engineer, Southwestern Bell Telephone Co.
Philadelphia	H. S. Phelps (A'21) engineer, special investigation and testing division, Philadelphia Electric Co.; Section secretary 1935–7
Pittsburgh	C. A. Powel (M'20) manager, central station engineering department, Westinghouse Electric and Manufacturing Co.; Section chairman 1935–6
Pittsfield	J. R. Meador (A'34) developmental engineer, General Electric Co.; Section secretary 1935–6
Portland	S. E. Caldwell (A'29) engineer, Pacific Power and Light Co.; Section chairman 1936–7
Providence	
Rochester	E. K. Huntington (A'23, M'35) electrical engineer, operating department, Rochester Gas and Electric Corp.; Section chairman 1935–6
St. Louis	C. A. Loveless (A'28, M'36) electrical sales engineer, C. B. Fall Co.; Section secretary 1936–7
San Antonio	E. G. Conroy (A'30) assistant chief dispatcher, San Antonio Public Service Co.; Section chairman 1936–7
San Francisco	E. M. Wright (A'20, M'31) assistant engineer, division of hydroelectric and transmission engineering, Pacific Gas and Electric Co.; Section chairman 1935–6
Saskatchewan	
Schenectady	H. H. Race (A'24, M'31) research engineer, General Electric Co.; Section chairman 1935–6
Seattle	E. B. Hansen (A'26) engineer, Pacific Telephone and Telegraph Co.; Section secretary 1935–6
Sharon	W. A. Sumner (A'30) section engineer in charge of small distribution transformer design, Westinghouse Electric and Manufacturing Co.; Section chairman 1935–6
Spokane	M. F. Hatch (A'33) assistant engineer, engineering department, Washington Water Power Co.; Section secretary 1934–5
Springfield	James J. Finn (A'24, M'31) superintendent, Roland T. Oakes Co.; Section chairman 1935–6
Syracuse	C. H. Bissell (M'32) chief engineer, Crouse-Hinds Co.; Section chairman 1935–6
Toledo	W. M. Campbell (A'28) electrical engineer, operating department, Toledo Edison Co.; Section secretary 1934–6
Toronto	V. G. Smith (A'26, M'35) assistant professor of electrical engineering, University of Toronto; Section chairman 1936–7
Urbana	H. A. Brown (A'16, M'26) assistant professor of electrical engineering, University of Illinois; Section chairman 1935–6
Utah	W. L. Winter (A'21) sales engineer, Westinghouse Electric and Manufacturing Co.; Section chairman 1936–7
Vancouver	D. M. Johnstone (A'21) superintendent of substation operation, British Columbia Electric Railway Co., Ltd.; Section secretary 1932–4
Virginia	J. S. Miller, Jr. (A'22, M'29) associate professor of electrical engineering, University of Virginia; student Branch counselor
Washington	H. W. Osgood (A'07, M'22) electrical engineer, Potomac Electric Power Co.; Section chairman 1936–7
Worcester	T. H. Morgan (A'23, M'31) professor and head of electrical engineering department, Worcester Polytechnic Institute; Section chairman 1934–5
Chairman, Sections Committee	I. Melville Stein (A'18, M'27) director of research, Leeds and Northrup Co., Philadelphia, Pa.

Table II—Record of Attendance of District Student Branch Counselor-Delegates

District	Delegate Name and Affiliation
1—North Eastern	F. M. Sebast (A'16, M'27) professor of electrical engineering for power, Rensselaer Polytechnic Institute, Troy, N. Y.
2—Middle Eastern	A. H. Forman (A'16, M'27) head of department of electrical engineering, West Virginia University, Morgantown
3—New York City	F. H. Pumphrey (M'25) professor of electrical engineering, Rutgers University, New Brunswick, N. J.
4—Southern	W. W. Hill (M'24) professor of electrical engineering, Alabama Polytechnic Institute, Auburn
5—Great Lakes	E. H. Freeman (A'09, M'13) professor of electrical engineering and director of electrical engineering option, Armour Institute of Technology, Chicago, Ill.
6—North Central	W. H. Gamble (A'27, M'33) associate professor of electrical engineering, South Dakota State College, Brookings
7—South West	J. S. Waters (A'21, M'28) instructor in electrical engineering, The Rice Institute, Houston
8—Pacific	E. F. Peterson (A'30) professor of electrical engineering, University of Santa Clara, Calif.
9—North West	G. R. Shuck (A'19, M'20) associate professor of electrical engineering, University of Washington, Seattle
10—Canada	
Chairman, committee on Student Branches	O. W. Eshbach (A'17, M'30) special assistant, personnel department, American Telephone and Telegraph Co., New York, N. Y.

subject might not have come up if that opening clause were carried out to its full extent by the national committees. Some of those do promote and others do not and have not...

"To present a preliminary report to the board of directors, I felt that the views of these conferences and of the people who responded to the questionnaires could be met by 2 actions, which I suggested to the board of directors. One was a resolution that required no change in by-laws...:

"Resolved, that the Sections be encouraged by all officers of the Institute, and by the technical program committee, and by the national technical committees in particular, to take a greater part in the technical activities of the Institute through such proper channels as they may select; examples being the formation of Section technical committees, the holding of specialized technical group meetings, the sponsoring of special technical courses, and similar arrangements which have been used successfully or may be worked out in the future."

"The board of directors agreed quite strongly with that resolution and passed it immediately...."

Chairman Stein reported that the second resolution "had to do with District activities, because there were delegates and members who felt that the District should play a greater part in Institute affairs." The proposal embodied the details incident to authorization and organization of District technical activities, and for their co-ordination with Section and national technical activities. However, after due consideration, the board of directors laid this second recommendation on the table, authorizing "the President in the meantime to refer it to the proper Institute committee to recommend a procedure in this matter which might be helpful." Thus, Chairman Stein reported, the proposal concerning District technical activities had been referred back to the Sections committee, and again was open for general discussion at the conference to determine what further action, if any, might seem desirable.

Extensive general discussion from the floor indicated the consensus of opinion to be that the actual facilities necessary for the satisfactory expansion of Section technical activities now were well provided, partly through the existing by-laws (as quoted) and partly through the previously mentioned resolution as adopted by the board of directors upon the recommendation of the Sections committee.

In response to Chairman Stein's request for a clarification of the conference's wishes in connection with the question of promoting District technical activities, the following motion was offered from the floor and promptly passed by unanimous vote:

Any action with regard to the formation of District technical committees shall be deferred until such time as there may be available a fuller knowledge of the workings of the Section technical committees.

In accordance with the program, F. P. West, chairman of the New York Section's power group, described the broadened activities of his Section which has 4 definitely organized subgroups: communication, illumination, power, and transportation. Mr. West explained that the New York Section thus has expanded its activities during the past 10 years for 2 principal reasons: "first, to give the younger engineers an opportunity to broaden themselves in the carrying on of the technical programs as well as by serving on committees; second, to expand the number of meetings and to accommodate such technical meetings as would be more in line with the types of work that the different groups were doing." (The activities program of the New York Section is described in some detail in the April 1936 issue of ELECTRICAL ENGINEERING, beginning on page 421.)

E. M. Wright, chairman of the San Francisco Section, described the history and development of the enlarged activities program of the San Francisco Section as typical of what might be done effectively by the smaller Sections. (A description of the activities program of the San Francisco Section, and an analysis of results, were published on page 454 of the April 1935 issue of ELECTRICAL ENGINEERING).

Counselor-Delegate Session

Five items were on the agenda of Chairman O. W. Eshbach of the committee on student branches for discussion at the meeting of that committee together with the student counselors:

1. Report of the chairman
2. Reports from the District chairmen
3. Report of committee on student papers
4. Report of committee on student prizes
5. Program for 1936–37.

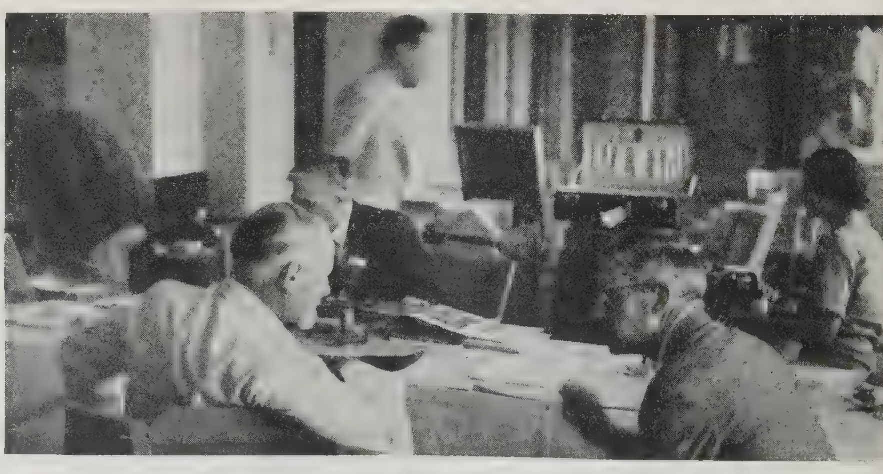
As the result of a long afternoon of discussion of the several subjects, the following recommendations were forthcoming:

1. IT IS RECOMMENDED that the procedure in selecting student prize papers for national and District awards be changed to include papers presented during the school year rather than the calendar year preceding the time of selection and awards. This would involve changes in the pamphlet on national and District prizes, and the following changes are recommended:

(*a*) that the sixth paragraph on page 6 of the pamphlet (edition of January 1935) be changed by the addition of the phrase "except that papers submitted for Branch prizes shall be for the period July 1 to June 30, and they must be submitted in triplicate to the District secretary on or before July 15 following the given period."

(*b*) that a second paragraph be added to the section entitled "Committees on Awards" on page 7 of the same pamphlet, to read as follows: "the District committees on awards shall submit in the second and third best Branch papers, for consideration by the national committee on award."

2. IT IS RECOMMENDED that weightings for the various items on which student papers are graded be as follows: analysis of subject, 20%; logical presentation, 20%; originality, 15%; unity, 10%; value in its field, 20%; value to electrical engineering, 15%.



Vice President W. H. Timbie giving attentive ear to Chairman C. W. Ricker of the New Orleans (La.) Section; J. H. Vivian (left), B. P. Rowe (seated) and other members of the registration committee in the background

3. It Is Recommended that an alternate be permitted to take the place of the chairman of the student Branch and to receive traveling allowance to District conferences on student activities when the student chairman is unable to attend.

4. It Is Recommended that the board of directors approve expenses, exclusive of travel, incurred in the organization and conduct of joint Branch conferences and student conventions, not to exceed $5 per year per Branch participating.

Closing General Session

Resolutions Adopted

The first item of business of the reconvened general conference was the presentation of a digest of the proceedings of the conference on student affairs, by Chairman O. W. Eshbach. This included the presentation of the 4 foregoing resolutions for the consideration of the general body. Mr. Eshbach explained the intended results of these resolutions as follows:

1. To enable Districts to make District awards early in the fall.

2. To provide a basis of grading that is more equitable to the student, particularly in view of his inevitable lack of practical professional experience. (This item was the subject of extensive discussion.)

3. To make possible the payment of the expense of a Branch delegate even though the chairman himself may be unable to attend.

4. It is believed that this activity should be supported by the Institute as a whole rather than to require it to be financed by the Branches themselves.

All 4 resolutions were adopted by unanimous vote.

The oft-discussed and related questions of membership dues and membership grades were brought up and discussed at length. Some expressed the belief that some extensive change should be worked out, but the prevailing opinion, as evidenced by the failure of suggested motions and resolutions to gain voting support, was that, although some modification might ultimately be worked out to advantage, no satisfactory program had been suggested so far. However, there was some general feeling that the question of membership dues should be entirely a fiscal matter, that the question of membership grades should continue to be considered strictly on the basis of professional qualification and personal initiative, and that these 2 questions should be separated "in the literature so that the grades of membership are not associated with the dues, but with the achievement of the individual." Accordingly, the following resolution was adopted unanimously:

Resolved that the present committee (the special committee to consider dues of associates and related matters) be requested to consider the feasibility of separating the matters of dues and grades of membership.

Improving Section Activities

The reports concerning the methods for improving Section activities that have been worked out successfully by the Philadelphia, Fort Wayne, and Kansas City Sections and, in accordance with the program of the conference, presented respectively by W. B. Morton (for H. S. Phelps), H. M. Witherow, and E. T. Mahood, are covered by a news item appearing elsewhere in this issue.

W. A. Sumner, chairman of the Sharon (Pa.) Section, summarized the miscellaneous suggestions that had been made to the program committee in connection with the development of the program for the Pasadena conference of officers, delegates, and members. Many of the points mentioned were covered in the discussions at Pasadena, others by reports of past conferences or other material that has been published from time to time in Electrical Engineering.

President-Elect MacCutcheon's address before the conference is scheduled for publication in a subsequent issue.

Fort Wayne, Kansas City, Philadelphia Sections Broaden Activities Programs

Effective methods have been worked out by many Sections for improving their activities programs and for providing ways and means for more individual members to participate in Section and other Institute affairs. To effect an exchange of ideas and to reflect credit for constructive initiative where such credit is due, Electrical Engineering has published such reports of these efforts as have become available. The essential substance of 3 such reports—presented as part of the scheduled program of the conference of officers, delegates, and members held in connection with the Institute's summer convention at Pasadena, Calif., June 22–26, 1936—is reflected in the following paragraphs.

Kansas City Section
Strengthen Meetings Program

In speaking on his assigned subject "Methods by Which a Section May Arouse and Retain the Interest of More Members," Chairman E. T. Mahood of the Kansas City Section outlined the several special efforts that have been made recently by the Kansas City Section to accomplish this 2-fold objective. These included:

1. Election of officers in the spring, and full use of the summer period for organizing the fall program.

2. Development of an *active* executive committee, and its enlargement to include prominent members.

3. Development of a meeting schedule based upon the results of an analytical study of the differing interests of section members.

4. Observing punctual meeting hours (7:15–9:00 p.m.) and preceding the meetings with a dinner (6:15 p.m.). This has been found to be convenient alike for in-town members and for those who come in from as far away as 150 miles.

5. Enlargement of meeting notice from a postal card to a letter-size sheet giving more information.

6. "Not being afraid to spend some money in connection with meetings" to provide extra features of attraction and to underwrite partially the cost of student attendance.

7. Holding monthly meetings, but keeping the dates subject to flexible arrangement to accommodate any special speakers that may be available in the territory.

8. Stimulation of wider membership participation by adoption of plan of having 2 10-minute talks each meeting by Section members on some topic of personal or local interest.

9. A special dinner meeting and program once a year attended by members and wives.

Philadelphia Section Reports
Sponsorship of Educational Courses

Introduced by H. S. Phelps, secretary of the Philadelphia Section, who was scheduled to speak on the subject, W. B. Morton of the Philadelphia Section spoke on the assigned topic "Section Educational Courses." He described "the task of the local Section" as 2-fold: "first, to make. . . . members conscious of the advantages that A.I.E.E. membership offers; and, second, to work continually toward increasing the services rendered to each member by his local Section to provide more tangible returns for his dues. These tangible returns will stimulate interest in the Section and tend to create a desire to become affiliated with the organization instead of fostering the negative reaction of some that affiliation with the Institute is merely an unprofitable obligation that one assumes in return for the privilege of being an engineer.

"As a start in this direction, the Philadelphia Section organized the 'related activities committee' to function as an entirely new service to members, devising and conducting new activities, such as educational courses and inspection trips. It was believed that these activities not only would provide a beneficial technical service to members, but would result in greater personal interest in the Sections through the medium of additional opportunities for the individuals to get together and meet other members of the Sections. Educational courses were considered to be a very promising activitity because of the definite need of most engineers for review instruction. . . . Thus, by providing an opportunity for our members to obtain this needed instruction, it was believed that we would not only help to build interest in the Sections, but also would increase the member's usefulness and elevate his individual professional status by improving his education. . . . The first course introduced was 'Electronics and Electron Tubes'. . . . Few engineers have retained more than a limited conception of the fundamentals of electronics.

"Notice of the electronics course was brought to the attention of members by means of a broadcast flyer similar to a meeting notice. . . . The response. . . . was so enthusiastic that. . . . a second class was necessary to accommodate the overflow. A total of 51 enrollments were received. . . . about 10 per cent of the membership."

The charge for the course was $12 for 18 2-hour evening periods, based upon actual cost and the original estimate of securing 23 class members; the actual registration of 51 resulted in the accumulation of $118 surplus. Reporting further, Mr. Morton stated that: "the selection of a competent instructor maintained interest throughout the course as evidenced by the attendance record of more than 97%. . . . members of the classes were engineers from

Past-chairmen of the San Francisco Section present at the summer convention numbered 14, of whom 13 are pictured: standing, left to right—W. C. Smith, 1933–34; P. B. Garrett, 1930–31 (A. W. Copley, vice president 1930–31); J. C. Clark, 1918–19; J. A. Koontz, Jr., 1923–24; W. P. L'Hommedieu, 1921–22; E. M. Wright, 1935–36; seated, left to right)—F. R. George, 1924–25; D. I. Cone, 1926–27; E. A. Crellin, 1931–32; W. L. Winter, 1927–28; S. J. Lisberger, 1910–11; A. M. Bohnert, 1934–35; H. H. Henline, 1922–23; not shown—L. F. Fuller, 1929–30

all levels in the profession, including junior engineers, supervisors, and executives from 18 different companies." Mr. Morton reported that, on the basis of 150 returns from 550 questionnaire cards mailed to the Section membership, the electronics course will be repeated next year and, in addition, a mathematical review course and an electrical theory course will be added. In emphasizing the importance of capable instructors he said further: "it cannot be too strongly emphasized that the success of the course, once properly organized, depends.... upon the ability of the instructor to hold the interest of the class. In selecting the instructors, each applicant is required to submit with his application a complete outline covering the scope of the course he desires to teach....

"The conducting of educational courses by the A.I.E.E. has been criticized in some cases as being in open competition with accredited schools and colleges.... There is no competition involved since the committee in charge of these activities co-operates with local school faculties and restricts the educational features offered to those not readily obtainable in the regular night schools. Moreover, our review courses are designed to prepare the class members for the postgraduate work given by local universities.... To promote further co-operation, the educational work of our related activities committee is supervised by a subcommittee on education comprising 2 professors from the faculties of local colleges and 2 engineers from the staffs of local manufacturing companies, all of whom are experienced in teaching and teaching methods...."

According to Mr. Morton's report, "another worth-while related activity is the inspection trips program....important because of the opportunity for members to get together in the informal atmosphere afforded by outings which takes them away from their every-day environment. Two major inspection trips were conducted. . the Philadelphia Electric Company's 165,000 kw Richmond generating station. . . (and) jointly with other societies to the Bethlehem Steel Company's plant in Bethlehem, Pa.; announcement of the Bethlehem trip was received with such enthusiastic interest that requests for reservations exceeded all accommodations. Plans are now actively under way for a trip to New York next Fall to inspect the Cunard Line's "Queen Mary," which trip will be followed by others now in process of planning. "The success of the 'related activities' sponsored by the Philadelphia Section this year demonstrates the need for this type of service.... Restriction of enrollment... already has had a beneficial effect (upon membership)... restriction (on inspection trips) is being seriously considered as a further inducement for prospective members to become affiliated with the Section....

"...Philadelphia Section very definitely believes that the related activities have enhanced the activities of the Section, and that they have answered in part at least the question of 'Why should I join the A.I.E.E.?'"

Fort Wayne Section Reports Participation in Civic Affairs

H. M. Witherow, Chairman of the Fort Wayne (Indiana) Section, in speaking on the scheduled topic "Co-operation of Sections with local Civic and Public Welfare Organization," described the efforts of the Fort Wayne Section to take a more active and contructive part in local civic affairs. Referring to paragraph 16 of the A.I.E.E. Code of Principles of Professional Conduct he said:

"It seems to me that the position which the engineering profession holds in society and in the public mind could be enhanced by a more active participation of engineers, as individuals and as groups, in civic affairs of a nonpolitical nature. Engineers are pre-eminently fitted by education and background to lead in molding public opinion. They have learned to think mathematically rather than emotionally. Given a set of facts, or data, or circumstances, and using engineering methods they will sift and analyze, separate and classify, and on the basis of evidence available reach conclusions that are sound. Certainly such leadership is safer than one motivated solely by political expediency.... It has been the habit of engineers...to remain in the background and to take little part in civic affairs....The Local Sections of the A.I.E.E., especially the smaller ones and those composed largely of corporation employees, can serve a real purpose in fostering interest in civic affairs and in keeping the membership informed in regard to opportunities for service.... Discussion of questions of community interest as a part of regular meetings or in special meetings should stimulate interest and provide the background for active participation of individual engineers in civic affairs."

Mr. Witherow cited the Fort Wayne Section's initial efforts in this direction, which includes active co-operation with the local chamber of commerce, the scheduling of speakers on civic topics for Section meetings, visits by a Section representative to all high schools for the purpose of talking with prospective science graduates, the furnishing to the several high schools of copies of the Engineering Foundation's pamphlet *Engineering, A Career, A Culture*. The Section also is considering participating in the formation of a Fort Wayne Engineers Club for "there are many ways in which such a club could be of service in the community. There are many improvements to be made in which engineering leadership would be invaluable.... (such as) the elimination of smoke, the suppression of unnecessary noise, the improvement of traffic conditions, the beautification of parks and river banks, etc."

A.I.E.E. Directors Meet During Summer Convention

The regular meeting of the board of directors of the American Institute of Electrical Engineers was held at the Huntington Hotel, Pasadena, Calif., on June 24, 1936, during the annual summer convention.

Present: *President*—E. B. Meyer, Newark, N. J. *Past-President*—J. B. Whitehead, Baltimore, Md. *Vice Presidents*—Mark Eldredge, Memphis, Tenn.; R. H. Fair, Omaha, Neb.; N. B. Hinson, Los Angeles, Calif.; F. O. McMillan, Corvallis, Ore.; F. J. Meyer, Oklahoma City, Okla.; G. G. Post, Milwaukee, Wis.; W. H. Timbie, Cambridge, Mass. *Directors*—H. B. Gear, Chicago, Ill.; C. R. Jones, New York, N. Y.; P. B. Juhnke, Chicago, Ill.; G. A. Kositzky, Cleveland, Ohio; W. B. Kouwenhoven, Baltimore, Md.; Everett S. Lee, Schenectady, N. Y.; A. H. Lovell, Ann Arbor, Mich.; L. W. W. Morrow, New York, N. Y.; A. C. Stevens, Schenectady, N. Y. *National Treasurer*—W. I. Slichter, New York, N. Y. *National Secretary*—H. H. Henline, New York, N. Y. Present by invitation: *Officers-elect*—A. M. MacCutcheon, Cleveland, Ohio; C. A. Powel, East Pittsburgh, Pa.; and R. W. Sorensen, Pasadena, Calif.

Minutes of the board of directors meeting of May 25, 1936, were approved.

Report was presented and approved of a meeting of the board of examiners held

June 10, 1936. Upon the recommendation of the board of examiners, the following actions were taken: 5 applicants were transferred to the grade of Fellow; 17 applicants were transferred and 15 were elected to the grade of Member; 94 applicants were elected to the grade of Associate; 96 Students were enrolled.

The finance committee reported disbursements from the general fund for the month of June amounting to $22,996.79, and from the Lamme Medal fund in connection with the award of the 1935 medal amounting to $280.30. Report approved.

Chairman Everett S. Lee of the membership committee mentioned the report of the committee for the fiscal year which ended April 30, 1936, and reported that a few more applications for membership were received during the month of May of this year than in May of last year.

Report was made of the appointment, upon nomination by the standards committee, of Professor D. L. Curtner as an alternate representative of the Institute on the sectional committee on transformers of the American Standards Association.

The standards committee reported acceptance of an invitation for the Institute to be represented on the ASA sectional committee on radio-electrical co-ordination being organized by the Radio Manufacturers Association, and the appointment, upon nomination by the standards committee, of Prof. R. W. Warner as representative and Prof. F. O. McMillan as alternate on this sectional committee. The board approved the action of the standards committee.

In accordance with a recommendation of the standards committee, approval was given to a further revision of a proposed standard for "Railway Motors and Other Rotating Electrical Machinery on Rail Cars and Locomotives" as reported by sectional committee *C*-35 on railway motors and other rotating electrical machinery.

An invitation to be represented at the inaugural ceremonies of Grover C. Dillman as president of The Michigan College of Mining and Technology was accepted, and Prof. J. F. H. Douglas was appointed the Institute's representative upon this occasion.

In connection with the summer convention, held at the Huntington Hotel, Pasadena, Calif., June 22–26, the board adopted resolutions of appreciation of the effective services of the general convention committee and of the various subcommittees, and of the ladies' committee, and also expressed its appreciation of the co-operation of the Huntington Hotel, The Chamber of Commerce of Pasadena, and the Henry E. Huntington Library.

President Meyer expressed his appreciation of the assitsance which he had received from the members of the board during his administration.

Other matters were discussed, reference to which may be found in this or future issues of Electrical Engineering.

Mabel Macferran Rockwell, energetic chairman of the women's committee, in conversation with D. C. Jackson, Jr., of Chicago, Ill.

Six Technical Conferences Held During Summer Convention at Pasadena

In response to popular demands growing out of their successful innovation in connection with the 1935 summer convention at Ithaca, N. Y., 6 informal technical conferences were held in connection with the 1936 summer convention in Pasadena, Calif. These conferences were scheduled primarily for the benefit of the younger members of the Institute and the technical specialists in the fields covered by the conference subjects: High voltage X-ray tubes and allied apparatus, carrier current, mechanical properties of electrical conductors, synchronous machines, general transformer problems, and electron tubes in industry. Operated on the basis of no set program, the conferences were open for a general interchange of ideas and for the discussion of any particular problems or other matters of special interest to those attending.

R. N. Conwell (left) of Newark, N. J., in deep consultation with G. H. Hagar of San Francisco; J. C. Jones (right) enjoying a brief respite from registration desk duties, watching the women's putting contest

Following are brief news reports covering 3 of these conferences; reports of the others may become available for publication in a subsequent issue.

Mechanical Properties of Electrical Conductors

By F. C. Lindvall, Chairman

This technical conference on mechanical properties of electrical conductors was intended to stimulate interest and discussion relative to such properties as are factors in vibration analyses. One of those properties that is of considerable importance is conductor damping, and that little is known about it was evidenced at the regular session on conductor vibration. Accordingly, a good deal of discussion was devoted to damping—that inherent in the metal itself, and that due to structure of the conductor. Results of theoretical and experimental work were presented, together with practical comments pertaining to cable manufacture and use. The discussion thus reflected various viewpoints—those of physicist, metallurgist, manufacturer, and user—and led to the conclusion that sound information on cable damping is lacking.

Naturally, vibration leads to questions of fatigue limits for conductors, and some discussion was offered on the general fatigue problem. No definite conclusions were drawn save a highly important one: that discussions of this type should involve only terms that have been carefully defined. Unfortunately, much of the requisite terminology is not standardized.

Ideas were presented and discussed relating to a proposal for detailed mechanical standards for electrical conductors.

High Voltage X-Ray Tube

By J. P. Youtz, Chairman

Among the 30 or so persons attending the informal conference given over to a discussion of high voltage X-ray tubes and allied apparatus, were noted several students, several utility men, and several connected with manufacturers of other than X-ray equipment.

Dr. C. C. Lauritsen of the Kellogg Million Volt X-Ray Laboratory at California Institute of Technology, described the installation there, covering its operation, purpose, and control. Subsequent discussion covered a wide variety of questions concerning X-ray practice and equipment, ranging from mechanical to therapeutic in scope, and including questions as to the trend and merits of a-c versus d-c tube operation, less being said in favor of d-c operation for general medical work.

Following the conference, Doctor Lauritsen conducted the group on a special tour of the Kellogg installation, his installation for the transmutation of matter, and the d-c 30 kw gyrating-target tube of Doctor DuMond, all at California Institute of Technology.

Electron Tubes in Industry

By F. E. Terman, Chairman

More than 60 actively interested persons were in attendance at the technical conference devoted to a discussion of the uses and applicability of electronic devices. Although none in attendance had had extended experience in the design of such equipment, many had had experience in the application of it. The discussion, therefore, centered in general around the uses for electronic devices, and their limitations and possibilities.

Principal topics considered were tube-controlled welders, tube-controlled feeder

equipment, photo-electric devices of various sorts, and miscellaneous devices employing electron tubes. The discussion concerning welders centered around the advantages of tube control for types of work requiring accurate control, it being pointed out that tube-controlled equipment is the only satisfactory means that has been devised for making welds in the aluminum alloys used in aircraft work. The so-called "ignitron" came in for considerable discussion in this connection since this represents one of the newer types of electronic devices to come into practical use.

With reference to theater lighting equipment, the discussion was concerned primarily with the practical advantages of tube control, from the operating point of view, as compared to resistance control.

A considerable part of the discussion concerning miscellaneous photo-electric devices centered about the question of economic justification for such devices. Representatives of the larger manufacturing companies contended that the possibilities of electron tubes have been overemphasized in many cases, stating that frequently it was possible to perform necessary operations mechanically with increased simplicity and reliability; contended also that the engineering and development costs required for special applications of electronic devices were so high that the future for such devices was not particularly promising. Disagreement with this latter view was voiced by some who held the belief that the larger concerns were not set up to handle special jobs economically and that there was a very wide field for the development and application of such special electronic devices that is open to individuals and to small concerns with flexible organizations and small overhead expenses.

It was interesting to note that the average age of those in attendance was lower than in most of the regular technical sessions, and that there was a more active participation by the younger men. Also, several were in attendance who came to Pasadena especially for this conference.

South West District Meeting at Dallas

As previously announced, a 3-day meeting of the South West District of the A.I.E.E. will be held in Dallas, Texas, October 26–28, 1936; headquarters will be at the Adolphus Hotel. As an added attraction the $25,000,000 Texas Centennial Exposition will be in full swing at that time. Here the dramatization of the onward march of a people in art, science, commerce, industry, education, and culture will be graphically depicted, and the story of cattle, cotton, and oil, which have raised Texas to the forefront of economic importance in a century, will be told in graphic exhibits. Dallas, a smartly cosmopolitan city, with its business center, residential sections, parks, and fine hotels, also provides an ideal location for the meeting.

A diversified program, which will have a special appeal to engineers of the South West, is being arranged by the local papers committee under the chairmanship of L. E. Cook. Some of the interesting subjects to be presented and discussed are: rural electrification, experience with a modern protective relay system, sub-station grounding practices, lightning and surge protection, electric power in the petroleum industry, and electric arc welding. In addition, there will be popular lectures on electronic theory and on lighting by well-known authorities in these fields.

The personnel of the District meeting committee making the arrangements is as follows: L. T. Blaisdell, vice president, A.I.E.E. South West District, *chairman;* F. J. Meyer, B. D. Hull; E. W. Burbank, hotels and registration; L. E. Cook, meetings and papers; A. B. Emrick, entertainment and reception; E. T. Gunther, finance; H. G. Mathewson, transportation and inspection; John Oram, attendance and publicity; J. S. Waters, chairman, committee on Student activities, 1936–37.

ECPD Promotes Vocational Guidance

For the benefit of high school students contemplating the study of engineering, the Associated Technical Societies of Detroit, Mich., recently held its first annual guidance meeting at which 123 boys and their parents were given an opportunity to consult representatives of various branches of the engineering profession. The conference was an outgrowth of the activities of the committee on student selection and guidance of the Engineers' Council for Professional Development, and was typical of guidance meetings which ECPD is promoting in other areas through local associations of engineers.

The conspicuous success of the Detroit meeting was due to careful advance planning by the Associated Technical Societies, the hearty co-operation of its 12 constituent groups, and the support of the Board of Education of the City of Detroit. The first step was to stimulate interest in the project among the technical societies of Detroit and to obtain from them the names of counselors who would participate in the guidance undertaking. At the same time a representative of the Board of Education explained the project to the public school authorities and secured their assistance and support. At a dinner meeting of representatives of all interested groups the general purposes of ECPD were explained, particularly the aims of the committee on student selection and guidance. Counseling groups were organized and instructed, and final plans were made for the meeting with high school students and their parents.

This meeting was attended by 220 people including 123 boys. The presiding officer was E. A. Danse, chief metallurgist of the Cadillac Motor Car Company, who has had long experience in work with boys, and who effectively explained the purposes and plan of the meeting. Copies of "Engineering—A Career, A Culture," a pamphlet distributed by ECPD, were given to all boys present.

The principal address was given by C. F. Hirshfeld (A'05), chief of research of the Detroit Edison Company and a past-chairman of ECPD. He distinguished between the fields of engineering, such as mechanical, electrical, etc., and the allied professions on the one hand, and on the other, functional activities, such as design, research, sales, which are common to engineering and the allied professions in general, leaving detailed consideration of professional divisions to take place in the conferences.

Following Mr. Hirshfeld's address, all present adjourned to the separate conference rooms assigned to the various societies. In these rooms, counselors of the societies met with those students who were interested in the corresponding professional division. These conferences were well attended except for 1 or 2 professional divisions in which local numbers are small. The procedure in the various conference rooms was for the chairman or some of his associates, or both, to address the students briefly in explanation of their division of the profession. Thereupon students from the group asked questions, which were answered by the counselor in the room best qualified by experience and training to supply the requested information. Personal and private interviews between counselors and students followed.

Local engineering groups in other parts of the country desirous of undertaking a guidance project can obtain further details on the Detroit meeting from Dean C. J. Freund, University of Detroit, Detroit, Mich. General instructions and assistance may be obtained from Dean R. L. Sackett, Pennsylvania State College, State College, Pa., who is chairman of the ECPD committee on student selection and guidance.

1936 Lamme Medal Nominations Due Nov. 1

Attention is called again to the opportunity open to any member of the Institute to submit nominations for the 1936 Lamme Medal. All nominations must be received not later than November 1. (For further particulars, see ELECTRICAL ENGINEERING for June 1936, page 751.) The 1935 Lamme Medal was presented to Dr. Vannevar Bush, vice president of the Massachusetts Institute of Technology and dean of the school of engineering, at the opening session of the recent summer convention in Pasadena, Calif.

Air Conditioning Standards Adopted. Application engineering standards for air conditioning recently were adopted by the Air Conditioning Manufacturers' Association. These standards constitute "recommended practice" for ACMA members, pending the formulation of adequate national standards for air conditioning applications under sponsorship of the proper societies. It is expected that there will be some further minor modifications in these standards during the next few weeks. These interim standards are the result of consideration by leading air conditioning technicians representing the principal manufacturers of air conditioning equipment.

Rackham Engineering Foundation. Articles of incorporation of The Rackham Engineering Foundation were filed June 12, 1936, in the offices of The Michigan Corporation and Securities Commission by Standish Backus, Alex Dow (A'93, F'13, and member for life), Edsel B. Ford, Bryson D. Horton (A'14), and William S. Knudsen, who are trustees of the corporation appointed for life. The new corporation will have title to the $500,000 endowment created by the Horace H. Rackham and Mary A. Rackham Fund for the benefit of the engineering professions and allied arts and sciences in the Detroit area, and for the assistance of the public in meeting engineering problems. Under the plan adopted, the net income from the endowment will be paid to The Engineering Society of Detroit, incorporated April 15, 1936. The foundation will have a discretionary right to permit a portion of the endowment to be used to provide a permanent headquarters for The Engineering Society of Detroit. It will also have power to assign a portion of the income, not exceeding 25 per cent thereof per year, to pay the expenses of studying, investigating, and exploring the practicability or wisdom of any proposed, contemplated, or partially constructed public project in Detroit or vicinity involving engineering skill, judgment, or knowledge, and of reporting to or advising any public body, commission, or authority thereon. The late Horace H. Rackham accumulated his fortune as a director of the Ford Motor Car Company and as a result of engineering skill applied to the automotive industry. It was a recognition of this fact that prompted the Board of Trustees of the Horace H. Rackham and Mary A. Rackham Fund to create this endowment.

Marine Way at Great Lakes Exposition in Cleveland

Flag-bedecked masts line the broad Marine Way at the Great Lakes Exposition, which opened at Cleveland, Ohio, for 100 days on June 27, 1936. The accompanying illustration shows Marine Way at night, with the ends of the Automotive Building and of the Hall of Progress visible at the right. At the head of the promenade, a marine theater and horticultural exhibits extend along the lake front. This $25,000,000 exposition, designed to glorify the industrial, commercial, and cultural advantages of the 8 Great Lakes States, marks the hundredth anniversary of the incorporation of Cleveland as a city.

N.R.C. Division Holds Annual Meeting

The rôle of research in the various federal government departments and bureaus as carried on during the past two and a half years was the main topic of discussion at the seventeenth annual dinner meeting of the National Research Council's division of engineering and industrial research held on the evening of May 4, 1936, at the Engineers' Club, New York, N. Y. The meeting was attended by some 50 leading executives, engineers, and leaders of scientific research. The Institute was represented at the meeting by National Secretary H. H. Henline.

The chief speaker at the meeting was Frank B. Jewett (A'03, F'12, and past-president) president of the Bell Telephone Laboratories, New York, N. Y., whose subject was "Activities of the Science Advisory Board." Dr. Jewett reviewed the accomplishments of the board since its creation by President Roosevelt in July 1933, and forecast the progress that will be made in the future.

The Science Advisory Board is a body of leading scientists, which has been appointed from time to time since its original creation by President Wilson in 1916, to co-operate with governmental agencies to deal with specific problems in which scientific research can aid in their solution. Among the important problems on which the board has concentrated during the past $2^1/_2$ years are those having to do with: (1) the nation's railways, particularly the question of transverse rail fissures; (2) the question of changes in the United States patent system as it may be related to the stimulation of new industries; and (3) the matter of signaling to promote greater safety at sea.

Reports read at the meeting on projects sponsored by the division of engineering and industrial research included those by Chairman J. W. Barker (M'26, F'30) of the committee on bridging the gap between university and industry; Chairman W. H. Carrier, of the heat transmission committee; Chairman H. E. Dickinson, of the highway research board; Chairman J. B. Whitehead (A'00, F'12, and past-president) of the committee on electrical insulation; and Vice Chairman B. A. Bakhmeteff, of the committee on hydraulic friction.

Vannevar Bush (A'15, F'24) vice president of the Massachusetts Institute of Technology, was elected chairman of the division, to succeed Charles F. Kettering (A'04, F'14). Howard Poillon, president of the Research Corporation, was elected vice chairman of the division.

Manufacturing Leads in Absorbing Unemployed. Manufacturing has absorbed more unemployed workers during the past 2 years than any other branch of industrial activity, according to an analysis by the National Industrial Conference Board. Of the total reduction in unemployment between January 1934, and January 1936, 80.3 per cent is attributable to improved conditions in manufacturing industries. Unemployment in nonmanufacturing industries in the first month of 1934 constituted 66.6 per cent of the estimated total. Two years later it had increased to 71.2 per cent of the total. The situation outside of manufacturing, construction, and mining, appears to have become worse rather than better. Unemployment in manufacturing, according to the board's estimates, declined from 3,597,000 in January 1934, to 2,824,000 in January 1936, or approximately 22 per cent. The construction industry absorbed about 255,000 workers, representing a decline of 20 per cent in the number of unemployed in that field. Mining re-employed 26,000, or slightly more than 5 per cent of its proportion of unemployed workers. In the combined fields of trade, and transportation and communication, unemployment increased from 2,743,000 to 2,802,000 during the 2 year period. These 2 groups accounted for 25.4 per cent of the total volume of unemployment in January 1934, and 28.5 per cent in January 1936.

A.S.T.M. Awards Dudley Medal. The 1936 Charles B. Dudley Medal of the American Society for Testing Materials has been awarded to H. C. Mann, senior materials engineer, Ordinance Department, U.S. Government, Watertown Arsenal, for his paper "The Relation Between Tension Static and Dynamic Tests." This medal, which commemorates the name of the first president of A.S.T.M. (1902–09) is awarded to the author of the paper presented at the preceding annual meeting that is of outstanding merit and constitutes an original contribution on research in engineering materials. The medal was presented to Mr. Mann on July 1 during the 1936 annual meeting of A.S.T.M. in Atlantic City, N. J.

A. G. Wishon Electrical Pioneer, Dies

On June 17, 1936, Albert Graves Wishon, irrigation and hydroelectric pioneer of the West, died at his home in Fresno, Calif., at the age of 78. A native of Missouri, Mr. Wishon went to California in 1889, settling in Tulare. While working there as a realtor, he visualized the possibility of irrigating the fertile but arid land and of obtaining hydroelectric power from the mountain streams of California.

After many reverses and much ridicule, he launched, in 1899, what is said to be the first irrigation venture in which water was pumped by electric power. Under his continued pioneering efforts, the San Joaquin Valley was converted from near desert to a land of agricultural abundance, and the San Joaquin Light and Power Corporation, which he and several associates purchased while it was in receivership, grew from a single 2,000 horsepower powerhouse to a 173,325 kva system.

New York Section to Repeat Review Courses

As part of the educational program to be sponsored this fall by the power group of the New York Section, the related activities committee is arranging to repeat the review courses in structural planning and design and in electrical engineering. Applicants for New York State Professional Engineer's Licenses who intend to enroll for either or both of these courses in preparation for the State examinations in January 1937 may obtain information from the chairman of the committee, Mr. Otto W. Manz, Jr., at 55 Johnson Street, Brooklyn, N. Y. The classes, which will be open to nonmembers as well as members of the Institute, will be held at Institute headquarters in New York, and will begin immediately after Labor Day.

Annual Convention of Illuminating Engineering Society. The 30th annual convention of the Illuminating Engineering Society will be held at Buffalo, N. Y., from August 31 to September 3, 1936, with headquarters at the Statler Hotel. The twelfth annual lighting service conference will be held Monday, August 31, and the formal opening of the convention will take place the same evening. The lighting equipment exposition, which has become such an important feature of the convention, will be even better than in former years, according to a recent announcement.

Idaho Power Company Wins Coffin Award. For its demonstrated ability to co-ordinate efficient and profitable utility operation with the activities of irrigators and government agencies in the power field with its own efficient and profitable operation to the end that company and customer have benefited mutually, the Idaho Power Company, Boise, has received the annual award for 1935 of the Charles A. Coffin Foundation, established by the General Electric Company in 1922. The award, comprising the Charles A. Coffin gold medal, a certificate, and a check for $1,000 to be deposited in the treasury of the utility's employee welfare association, was received by K. M. Robinson, president and general manager of the Idaho company, during the recent annual convention of the Edison Electric Institute at St. Louis, Mo. The award is made annually for a distinguished contribution to the development of electric light and power for the convenience of the public and the benefit of the industry. Judges for this year were Thomas N. McCarter, president of the Edison Electric Institute; Karl T. Compton (F'31), president of Massachusetts Institute of Technology; and Frank W. Smith (A'05, M'12) chairman of the E.E.I. prize awards committee.

Examination for Naval Appointments. According to a recent announcement, an examination is to be held in the fall to fill vacancies in the commissioned grade of assistant civil engineer, Corps of Civil Engineers, United States Navy, with rank of lieutenant (junior grade). Existing vacancies will be filled as soon as possible by the appointment of candidates successfully passing the examination; those successful candidates not immediately appointed will be placed on a waiting list for a period of not greater than one year, from which list appointments may be made to fill additional vacancies. The examination will be open only to male citizens of the United States who comply with the following conditions: (*a*) a candidate shall have passed his twenty-second birthday and shall not have passed his thirtieth birthday on January 1, 1937; (*b*) a candidate must have received a degree from a college or university of approved standing, in some branch of engineering fitting him for the practice of engineering in the Corps of Civil Engineers, which practice is chiefly civil, mechanical, electrical, and architectural engineering; (*c*) a candidate must have had, on June 30, 1936, not less than 3 years of practice of engineering, at least 2 years of which is subsequent to receipt of his first engineering degree; and (*d*) a candidate must be of good moral character and repute. Those interested should write at once to the Chief of the Bureau of Yards and Docks, Navy Department, Washington, D. C. Applications must be received by the department before September 15, 1936.

Valuable Communication Library for Canada. According to a recent announcement, Donald McNicol (A'05, F'18) past-president of the Institute of Radio Engineers, has presented to Queens University, Kingston, Ontario, Canada, his comprehensive library of published books and technical papers on communication. These works include more than 1,000 historical and modern items on the subjects of telegraphy, submarine cables, telephony, radio, television, and talking-picture engineering. The library is a consolidation of several collections procured by Mr. McNicol, and includes numerous original documents covering invention and numerous historical items of which there are few if any duplicates. The collection will be housed in the Douglas Library at the university, for reference use, and will be known as the McNicol Library on Communication; it will be available to Canadian engineers and students for study and research.

ASME Nominates 1937 Candidates. Nominations for officers of The American Society of Mechanical Engineers for 1937 were announced during the recent semiannual meeting of the Society held in Dallas, Texas. Those nominated are as follows: *President*—J. H. Herron (M'35), president, James H. Herron Co., Cleveland, Ohio. *Vice Presidents*—J. A. Hall, professor of mechanical engineering, Brown University, Providence, R. I.; J. M. Todd (M'32) consulting engineer, New Orleans, La.; R. J. S. Pigott, staff engineer, Gulf Research and Development Corporation, Pittsburgh, Pa. *Managers*—E. W. Burbank (A'25, M'30) district manager, Allis-Chalmers Mfg. Co., Dallas, Texas; K. H. Condit, editor, *American Machinist*, New York, N. Y.; S. W. Dudley, dean of engineering, Yale University, New Haven, Conn.

Industrial Vacuum Tubes Being Standardized by ASA

Standardization of vacuum tubes for industrial purposes is now under consideration by a sectional committee (C60) of the American Standards Association. The scope of the work of this committee is defined as: "definitions, classifications, methods of rating and testing, dimensions, and interchangeability of vacuum tubes for power and industrial applications." The organization meeting of the committee was held May 29, 1935, and several meetings have been held since that time. At the November 27, 1935, meeting, a subcommittee was appointed for the purpose of collecting and reporting standards of definitions, graphical symbols, and letter symbols pertaining to vacuum tubes for industrial purposes that have been acted upon by other standardizing bodies and are ready for standardization by ASA. This subcommittee has drawn up a report containing (1) recommended definitions, letter symbols, and graphical symbols; and (2) a tabulation showing additions to, deletions from, and changes in the December 5, 1934, report of ASA subcommittee on electronics (13A), including explanations of recommended changes. Members interested are urged to obtain a copy of this report and to forward promptly to the ASA any comments or criticisms they wish to offer. A limited number of copies of the report is available from the American Standards Association, 33 West 39th Street, New York, N. Y.

Personnel of the committee and organizations represented are as follows: AIEE—Leo Behr (A'29) Leeds and Northrup Company, Philadelphia, Pa.; M. J. Kelly (M'26,

F'31) Bell Telephone Laboratories, New York, N. Y.; J. B. Russell (A'34) Columbia University, New York, N. Y. Association of American Railroads—J. V. B. Duer (A'15, F'29) Pennsylvania Railroad, Philadelphia, Pa. Electric Light and Power Group—R. N. Conwell (A'15, F'31) Public Service Electric and Gas Co., Newark, N. J.; H. W. Eales (A'17, F'25) Byllesby Engineering and Management Corporation, Chicago, Ill. Institute of Radio Engineers—B. E. Shackelford, RCA Radiotron Company, Harrison, N. J. National Electrical Manufacturers Association—L. W. Chubb (A'09, F'21) Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.; C. W. Pike, General Electric Company, Schenectady, N. Y.; Carroll Stansbury (M'25) Cutler-Hammer, Inc., Milwaukee, Wis.; Dayton Ulrey, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. Radio Manufacturers Association—J. C. Warner (M'34) RCA Radiotron Company, Harrison, N. J. U.S. Bureau of Standards—W. F. Snyder, National Bureau of Standards, U.S. Department of Commerce, Washington, D. C. Dayton Ulrey is chairman of the sectional committee, and J. B. Russell is secretary. Personnel of the subcommittee on definitions, graphical symbols, and letter symbols is as follows: C. W. Pike, chairman; B. E. Shackelford, M. J. Kelly, and J. C. Warner.

American Engineering Council

Survey of Engineers Statistics Published

The June issue of the *Monthly Labor Review*, published by the U.S. Department of Labor, contains the first summary of statistics on the "Survey of Engineers" conducted in August and September 1935, by the Bureau of Labor Statistics in collaboration with the committee on engineering and allied technical professions of the American Engineering Council in co-operation with more than 100 national, state, and local engineering societies. More than 50,000 questionnaires were returned to the Bureau of Labor Statistics for classification and codification. This is the first professional survey undertaken by the Bureau of Labor Statistics, and the returns are said to represent the largest sampling of the engineering profession ever made. An abstract of this report appears elsewhere in this issue.

The final report of this survey will present a very comprehensive analysis of the profession, including facts on education, distribution of engineers in both government and private employment, compensation, and a very complete picture of the engineering employment conditions for the period between 1929 and 1934. It is hoped that the final report will be available in the early fall.

Letters to the Editor

Crossing the St. Lawrence With Unstressed Cable Lengths

To the Editor:

The writer was much interested in the account in the February 1936 issue of ELECTRICAL ENGINEERING of "Crossing the St. Lawrence With Unstressed Cable Lengths," by Messrs. Mace and Thicke (pages 164–7).

It may be of interest to learn that history is repeating itself so far as this construction is concerned. Within one mile of the Kanawake-LaSalle crossing, upstream is a crossing erected in 1911 by the Canadian Light and Power Company, now affiliated with the other Montreal power interests. This crossing has a tower in the middle of the St. Lawrence River just below the Canadian Pacific Railway bridge and is carried from another part of Kanawake to Rockfield. The 2 spans were approximately 1,800 and 1,600 feet. The conductors were "copperweld," then made by the Duplex Metals Company in the United States, and were cut to the calculated unstressed lengths at the factory.

The conductors were laid by mounting reels on a barge and paying the cable out while the barge was towed by a launch. The cable was allowed to rest on the river bottom until the conditions were favorable for raising it.

Yours truly,

C. O. VON DANNENBERG (A'06, M'30)

Tata Iron and Steel Company, Ltd., Jamshedpur, India

Definition of Coercive Force

To the Editor:

Investigations of modern magnetic materials have carried us to a point where it is imperative to agree on an unambiguous definition of a physical conception which in the minds of the practical engineer and the physicist represent something quite different. This is the coercive force; and although this difference is tacitly acknowledged by all concerned to exist, no serious effort has been made to remove this dilemma (such it is in fact). Is coercive force to be defined as the magnetizing force for magnetization (I) equal to zero or induction (B) equal zero? So long as the electrical engineer has to do with magnetically soft materials, *e. g.*, in electrical machinery where the permeability is great, the question was indeed of no great consequence as in the definition for B, $B = 4\pi I + H$, the last term H is of small influence.

Recent studies of magnetic phenomena, however, and in particular the very important investigations of materials for permanent magnets and of highly magnetic powders, have shown that a clear distinction should be made as to whether the coercive force is for $B = 0$ or $I = 0$, because in such materials the difference between the 2 values which is negligible in soft materials becomes very considerable. The uncertainty has been recognized before and has been most clearly expressed by L. W. McKeehan in his paper "Magnetism in Discontinuous Media" (*Review of Modern Physics*, volume 2, October 1930, pages 477–575); in this paper he says:

> ". . . . Faraday's 'tube of force' was undoubtedly the root of all evil in this connection (i. e., this uncertainty—the author). To preserve these tubes unaltered in number as they were followed through various pieces of matter about the interior of which nothing much was known, it was necessary to invent for them a vector point function, B, called the magnetic induction, which could not be distinguished from H in what was fondly termed 'empty space,' but which differed markedly from H in 'ponderable matter.' To make matters worse, it soon appeared desirable to invent 2 more vector point functions for ponderable matter only, and one of them, in all innocence, was called the magnetic field intensity and given the symbol H in spite of the fact that it did not satisfy the equation—given above—by which alone H had been defined. The other new point function, the intensity of magnetization, I, did not usurp a place already occupied."

This states clearly the reasons for, and origin of, our present dilemma. Quite recently, Hans Neumann also pointed out the great practical importance of distinguishing between the 2 definitions of a single conception (in the description of a new apparatus, the coercimeter, for measuring the coercive force directly) in Archiv für Technisches Messen, volume 4, 1935, pages T64–T65.

Investigations and experiments carried on recently in the Bureau of Mines, Pittsburgh, Pa., station, by V. H. Gottschalk, C. W. Davis, and the writer have shown that the coercive force is in all probability much more than the mere negative definition usually applied to it: *e. g.*, in the "Standard Handbook for Electrical Engineers":

> "coercive force is the reversed magnetizing force which is just sufficient to reduce the residual induction to zero."

It has been demonstrated beyond almost any doubt that coercive force must be considered as a structural property of a material dependent on the surface of grain, and that this connection becomes clear not when induction but magnetization and the respective coercive force ${}_IH_c$ are considered.

Before publication of the data collected in these investigations it was deemed advisable to call attention to a condition

which requires a clear cut solution in the near future. It might well be a matter for consideration of the International Electrical Commission since the undesirable state of affairs is quite generally recognized.

Very truly yours,

MAX HARTENHEIM (A'25)
Consulting Engineer,
Edgewood, Pa.

Self-Excitation of a Frequency Converter

To the Editor:

In the December 1935 issue of ELECTRICAL ENGINEERING on page 1360 Mr. Hess claims in his paper on "Self-Excitation of a Frequency Converter" that a d-c machine could only be made self-exciting for alternating current by inserting into the field circuit capacitance great enough to compensate the inductive voltage drop at a given frequency.

I should like to point out that also without a capacitance a d-c machine (with laminated field structure) can be made self-exciting for alternating current and working on circuits containing only resistance and reactance. The only change necessary is to connect the machine as shown in figure 1. The rheostat for regulating the field of impedance Z_a (for a given frequency) carries not only the field current but also the load current.

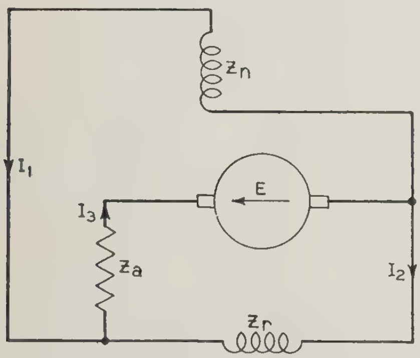


Fig. 1. Arrangement of circuits of d-c machine to produce alternating current

Assuming that an alternating current of frequency f and of sinusoidal form is generated and using the symbols

$E_1 = \varphi(I_1)$ = electromotive force of generator due to rotation in field produced by field coil carrying current (see figure 2)

$Z_a = R - j\omega L_a$

R = resistance of field rheostat and armature

L_a = self-inductance of field rheostat and armature

$Z_v = v_v - j\omega L_v$

v_v = resistance of load

L_v = self-inductance of load

$Z_n = v_n - j\omega L_n$

v_n = resistance of field coil

L_n = self-inductance of field coil

I_1 = current in field coil

I_2 = current in load circuit

I_3 = current in field rheostat and armature

$\omega = 2\pi f$

The equations for the steady state currents of the 3 circuits are

$$\varphi(I_1) - I_1 Z_n - I_3 Z_a = 0 \qquad (1)$$

$$\varphi(I_1) - I_2 Z_r - I_3 Z_a = 0 \qquad (2)$$

$$I_1 + I_2 - I_3 = 0 \qquad (3)$$

Solving for I_1 while regarding $\varphi\ (I_1)$ as known quantity,

$$I_1 = \varphi(I_1) \begin{vmatrix} 1 & 0 & Z_a \\ 1 & Z_r & Z_a \\ 0 & 1 & -1 \end{vmatrix} : \begin{vmatrix} Z_n & 0 & Z_a \\ 0 & Z_r & Z_a \\ 1 & 1 & -1 \end{vmatrix}$$

In the equations 1, 2, and 3 the frequency or ω is also an unknown quantity, so a fourth equation is needed, which is the relation between I_1 and $\varphi(I_1)$ given in graphic form in figure 2. Introducing complex quantities and assuming $L_a = 0$,

$$I_1[(v_n - j\omega L_n)(v_v - j_a L_v) + R(v_v - j\omega L_v) + R(v_n - j\omega L_n)] = \varphi(I_1)(v_v - j\omega L_v)$$

Separating real and imaginary terms

$$I_1(r_n r_r + R r_r + R r_n - \omega^2 L_n L_r) = \varphi(I_1) r_r \qquad (6)$$

$$I_1(r_r L_n + L_r r_n + L_r R + L_n R) = \varphi(I_1) L_r \qquad (7)$$

Equation 6 enables one to find the corresponding absolute values of I_1 and $\varphi(I_1)$ for $|\varphi(I_1)|$ is the no load characteristic of the d-c machine plotted as a function of $|I_1|$. The intersection of the characteristic with a straight line drawn from the origin under the angle α, with the abscissae axis such that $\tan\alpha = R + r_n + (R + r_n)\dfrac{L_n}{L_r}$ gives the absolute values $|I_1|$ and $|\varphi(I_1)|$. Inserting these in equation 6 furnishes as value for the frequency

$$f = \frac{1}{2\pi}\sqrt{\frac{|I_1|(r_n r_r + R r_r + R r_n) - |\varphi(I_1)| r_r}{|I_1|\ L_n L_r}}$$

For open load circuit $r_r = \infty$ and equation 6 after division by r_r reduces to the well known form for the d-c machine

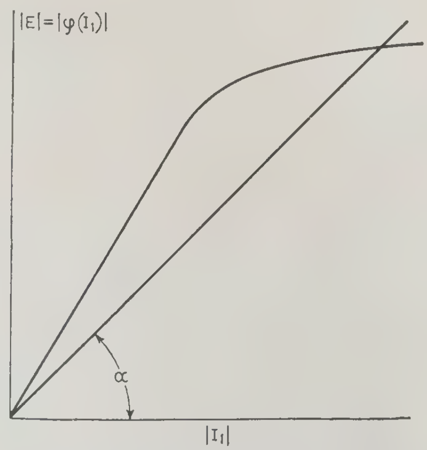


Fig. 2. Characteristic of self-excited machine showing method for determining | I1 |

$$|I_1|\ (R + r_n) = |\ \varphi(I_1)\ |$$

The frequencies of the alternating current generated in this manner are low as a rule. With the following values:

$r_r = 0.27$ ohm; $r_n = 19$ ohms;
$R = 1.15$ ohms; $L_n = 5.9$ henries;
$L_r = 1.32$ henries; $|\ I_1\ | = 3.6$ amperes;
$|\ \varphi(I_1)\ | = 95$ volts

a frequency of 0.25 is calculated.

Very truly yours,

LIONEL FLEISCHMANN
Office of American Representative of
Allgemeine Elektricitäts-Gesellschaft,
1 River Road, Schenectady, N. Y.

To the Editor:

Mr. Fleischmann's comment on the a-c self-excitation of a d-c generator is very interesting. It does, however, not appear to invalidate the statement in the author's paper to the effect that a-c self-excitation of "normal" d-c generators is not possible unless capacitances are inserted in the field circuit. Although it is true that Mr. Fleischmann's d-c generator is capable of a-c self-excitation, this generator can hardly be considered "normal" because its armature resistance is extremely high and the armature reactance negligibly small. Both assumptions favor a-c self-excitation. This is readily seen if the armature reactance of the d-c generator is taken into account in the equation of the self-excited frequency. By expressing in it $|\varphi(I_1)|$ in terms of the different resistances and reactances the equation reads, with Mr. Fleischmann's nomenclature and after a few simplifications:

$$f = \frac{1}{2\pi}\sqrt{\frac{R \cdot r_n - \left[(R + r_r)\dfrac{L_n}{L_r} + (r_r + r_n)\dfrac{L_a}{L_r}\right] r_r}{L_n \cdot L_r + L_a(L_r + L_n)}}$$

This equation shows that with increasing armature reactance L_a and with decreasing armature resistance R the numerator under the root decreases and finally becomes negative. For instance, with Mr. Fleischmann's numerical data of the load and the shunt field armature data equal to 1/1 to 1/10 of those of his load circuit, the calculated frequency is imaginary and a-c self-excitation not possible. These examples could be amplified, but the armature resistance of normal d-c generators is usually so small and the armature reactance so large that a-c self-excitation is impossible.

In concluding, it may be pointed out that Mr. Fleischmann's conclusions hold also if the armature resistance be replaced by an equivalent counter-compound winding, that is, one that counteracts the generator shunt field. It can also be shown that—again for inductive loads—its counter-part, the compound winding, tends to suppress a-c self-excitation. As many of the normal d-c generators are equipped with such windings, this effect of the compound winding is additional evidence that a-c self-excitation of these generators cannot occur although, as Mr. Fleischmann has pointed out, it can be made possible by a suitable design of the generator.

OSCAR HESS (A'30)
18 Clyde Street,
Belmont, Mass.

Personal Items

M. E. Strieby (M'22) carrier transmission research engineer, Bell Telephone Laboratories, Inc., New York, N. Y., with Lloyd Espenschied (A'18, F'30) co-author of the paper "Wide Band Transmission over Coaxial Lines," has been awarded the 1935 A.I.E.E. national prize for best paper in theory and research. Mr. Strieby is a native (1893) of Colorado Springs, Colo., and received the degrees of bachelor of arts (1914) at Colorado College, bachelor of science (1916) at Harvard University, and bachelor of science in electrical engineering (1916) at the Massachusetts Institute of Technology. During the year following his graduation from the Massachusetts Institute of Technology he was employed, as an engineer for the New York Telephone Company, New York, N. Y., and during 1917–19 he served in the signal corps of the U.S. Army. Mr. Strieby was employed by the American Telephone and Telegraph Company, New York, N. Y., in 1919, and became engaged in research on the transmission features of telephone repeaters and associated equipment. In 1929 he was transferred to the technical staff of the Bell Telephone Laboratories, and has been occupied with carrier transmission research studies since that time. He is a member of the Institute of Radio Engineers.

Lloyd Espenschied (A'18, F'30) radio transmission development director, Bell Telephone Laboratories, Inc., New York, N. Y., with M. E. Strieby (M'22) co-author of the paper "Wide Band Transmission over Coaxial Lines," has been awarded the 1935 A.I.E.E. national prize for best paper in theory and research. Mr. Espenschied was born at St. Louis, Mo., in 1889, and is an industrial electrical engineering graduate (1909) of Pratt Institute. Following his graduation, he was engaged as assistant engineer for the Telefunken Wireless Telegraph Company of America, and in 1910 he became development engineer for the American Telephone and Telegraph Company, New York, N. Y. From 1910 to 1915 his principal work was in the design of coils, transformers, and loading coil systems, and in 1915 he participated in long distance radiotelephone experiments, being located in Hawaii for a time for the reception of transmissions from Washington, D. C. In 1916 he was placed in charge of carrier current and radio transmission development, and he remained in charge of carrier current development until he was transferred to the Bell Telephone Laboratories in 1934. Mr. Espenschied has presented several papers before the Institute. He is a member of the Institute of Radio Engineers, and is active in that organization.

Gabriel Kron (A'30) general engineering department, General Electric Company, Schenectady, N. Y., recently received the honorary degree of master of engineering from the University of Michigan. Mr. Kron was born at Nagybanya, Hungary, in 1901, and received the degree of bachelor of science in electrical engineering at the University of Michigan in 1924. Following a brief connection with the U.S. Electrical Manufacturing Company, Los Angeles, Calif., he entered the employ of the Jeannin Electric Company, Toledo, Ohio, as a draftsman. In 1925 he became electrical designer for Robbins and Myers, Inc., Springfield, Ohio, and in 1928 he accepted a position as research engineer for the Lincoln Electric Company, Cleveland, Ohio. In 1930 Mr. Kron became consulting engineer for the United Research Corporation, Long Island City, N. Y., and after 4 years was engaged by the General Electric Company. He has written several technical articles and has presented a paper before the Institute on the application of tensors to the dynamics of rotating electrical machines. In 1935 Mr. Kron received the award of the George Montefiore Foundation of the University of Liege, Belgium.

C. W. Kellogg (A'19, M'23) chairman of the board, Engineers Public Service Company, New York, N. Y., recently was elected president of the Edison Electric Institute for the 1936–37 term. Mr. Kellogg was born at Philadelphia, Pa., in 1880, and received the degrees of bachelor of science (1902) and master of science (1903) at the Massachusetts Institute of Technology. During 1905–06 he served as manager of the Edison Electric Illuminating Company of Brockton, Mass., and from 1906 to 1914 he held a similar position with the El Paso (Texas) Electric Railway Company. He also served as manager of the Railway Light Companies of Port Arthur, Texas, and Beaumont, Texas, during the period 1910–14. In 1914 Mr. Kellogg became manager of the Mississippi River Power Company, Keokuk, Iowa, and was appointed district manager of Stone and Webster, Inc., in 1916. He held the 2 positions concurrently until 1919, when he was transferred to the Boston, Mass., offices of Stone and Webster and became engaged in work on appraisals and reports, including investigations for the Interborough Rapid Transit Company New York, N. Y., New York (N. Y.) Railways Company, and the Conowingo project on the Susquehanna River. In 1925 he went to New York to become president of the Engineers Public Service Company, which was established in that year, and he has been chairman of the board of that organization since 1934. He is a member of the American Transit Association.

Bancroft Gherardi (A'95, F'12, Edison Medallist '32, past-president, and member for life) vice president and chief engineer, American Telephone and Telegraph Company, New York, N. Y., recently was granted the honorary degree of doctor of engineering by Worcester Polytechnic Institute. Mr. Gherardi is a native (1873) of San Francisco, Calif., and received the degree of bachelor of science (1891) at the Polytechnic Institute of Brooklyn, N. Y. In 1893 he received the degree of mechanical engineer, and in 1894 the master's degree in mechanical engineering at Cornell University. In 1895 he entered the employ of the New York (N. Y.) Telephone Company, where he was engaged in various problems in planning and supervision. In 1899 he became engineer of the traffic department of that company, and in 1901 he was appointed chief engineer of the New York and New Jersey Telephone Company. He was assistant chief engineer of the New York Telephone Company, 1906–07. Mr. Gherardi became engineer of plant of the American Telephone and Telegraph Company (1907–18), acting chief engineer and chief engineer (1918–20), and since 1920 he has been vice president and chief engineer. He is a director of several telephone companies. He has been an active participant in Institute affairs, having served as manager, 1905–08 and 1914–17, vice president, 1908–10, president, 1927–28, and as a member of many of the Institute's committees. He is a member of several important technical societies in the United States.

F. E. Harrell (A'26, M'35) assistant chief engineer, Reliance Electric and Engineering Company, Cleveland, Ohio, coauthor of the paper "D-C Braking of Induction Motors," with W. R. Hough (A'35) has received honorable mention in the 1935 A.I.E.E. national prize awards for initial paper. Mr. Harrell is a native (1903) of Logansport, Ind., and received the degree of bachelor of science in electrical engineering at Purdue University in 1924. He was granted the professional degree of electrical

M. E. STRIEBY

C. W. KELLOGG

LLOYD ESPENSCHIED

engineer by Purdue University in 1929. Following his graduation in 1924 he became a sales engineer for the Reliance Electric and Engineering Company, and served in that capacity until he was transferred to the general engineering department in 1927. In 1929 Mr. Harrell was appointed chief draftsman, and in 1932 he was placed in charge of the design of a-c machinery. He has held his present position since 1934. He is a member of the Institute's committee on applications to iron and steel production.

H. M. Cushing (A'06, F'35) chief engineer, Buffalo (N. Y.) General Electric Company, has received the 1935 A.I.E.E. North Eastern District prize for initial paper for his paper "Design and Operation of Huntley Station No. 2." Mr. Cushing was born at Rockport, Ind., in 1875, and received the degree of bachelor of science in electrical engineering at the Massachusetts Institute of Technology in 1899. Following a brief preliminary training he was employed by the General Electric Company, Schenectady, N. Y., first as a test engineer, and later as a member of the local companies committee and an engineer in the central station engineering department. In 1904 Mr. Cushing was transferred to the New York, N. Y., offices of the General Electric Company, where he remained for 6 years; in 1910 he was transferred to the Buffalo offices as a local sales engineer. He has been with the Buffalo General Electric Company since 1915, first as mechanical engineer in charge of steam and mechanical design, and, since 1922, chief engineer. Mr. Cushing is a member of the Institute's committee on power generation. He is a member of The American Society of Mechanical Engineers and American Society for Testing Materials.

W. W. Lewis (A'09, M'13) electrical engineer, central station engineering department, General Electric Company, Schenectady, N. Y., recently received the honorary degree of doctor of science from the University of Colorado. Mr. Lewis was born in 1881 at Denver, Colo., and received the degrees of bachelor of science in electrical engineering (1907) and electrical engineer (1923) at the University of Colorado. He received the degree of master of science at Union College in 1923. Following the completion of his undergraduate studies, he entered the employ of the General Electric Company, Schenectady, N. Y., as a test engineer, and his service with that company has been continuous. He is the author of many technical papers and a textbook on transmission line engineering. Mr. Lewis served on the Institute's committee on power transmission and distribution, 1924–25, and has been a member of the committee on standards since 1934. He is a member of Tau Beta Pi.

N. S. Hill, Jr. (A'96 and member for life) president, Hackensack (N. J.) Water Company, recently was elected to honorary membership in the American Water Works Association. Mr. Hill was born at Baltimore, Md., in 1869, attended Georgetown University, and graduated from Stevens Institute of Technology in 1892. Following his graduation, he became an inspector for the Chicago and South Side Elevated Railroad Company, Chicago, Ill.; later, he became engineer-secretary of the Sewerage Commission, Baltimore, Md., engineer for the Baltimore Electric Subway Commission, and chief engineer of the Charleston (S. C.) Consolidated Railway, Gas, and Electric Company. Since 1901 he has maintained consulting engineering offices at New York, N. Y., and has been associated with several municipal water companies. In 1926 he was appointed president of the Hackensack Water Company. Mr. Hill is a past-president of the American Water Works Association and a member of the American Street Railway Association, American Geographical Society, American Institute of Consulting Engineers, American Society of Civil Engineers, The American Society of Mechanical Engineers, and American Society for Testing Materials.


D. G. GEIGER


H. M. CUSHING


L. M. OLMSTED

W. R. Hough (A'35) chief draftsman, Reliance Electric and Engineering Company, Cleveland, Ohio, has received honorable mention with co-author F. E. Harrell (A'26, M'35) for the paper "D-C Braking of Induction Motors" in the 1935 A.I.E.E. national prize awards for initial paper. Mr. Hough was born at Kalamazoo, Mich., in 1907, and received the degree of bachelor of science in electrical engineering at the University of Michigan in 1929. Following his graduation he was employed in the training course of the Reliance Electric and Engineering Company, and his association with that company has been continuous since that time. During 1930–31 he was mechanical designer; subsequently he held the positions of a-c motor designer, assistant to chief designer of a-c motors, and (1934–35) engineer in charge of experimental laboratories. In 1935 Mr. Hough was made chief draftsman.

D. G. Geiger (A'25, M'36) transmission engineer, Bell Telephone Company of Canada, Toronto, has received the 1935 A.I.E.E. Canada District prize for best paper for his paper "The Transmission Design of Telephone Systems." Mr. Geiger was born at Ottawa, Canada, in 1900, and received the degrees of bachelor of science in electrical engineering (1922) and bachelor of science in mechanical engineering (1923) at Queen's University. During 1923–24 he served as a demonstrator in the department of electrical engineering, Queen's University, and from 1926 to 1928 he was a lecturer. Mr. Geiger had been associated with the Bell Telephone Company of Canada during summer recesses for several years, and in 1928 he accepted a position as an engineer in the transmission division of that company, with offices at Montreal. After a brief period as transmission engineer in the eastern area, he was transferred to the Toronto offices in a similar capacity in 1930. Mr. Geiger is active in local Institute affairs, being secretary of the Toronto Section. He is a member of the Engineering Institute of Canada and the Institute of Radio Engineers.

L. M. Olmsted (A'30) junior engineer, Duquesne Light Company, Pittsburgh, Pa., has received the 1935 A.I.E.E. Middle Eastern District prize for best paper for his paper "Improving Voltage Regulation on Distribution Feeders." Mr. Olmsted was born at Saratoga, N. Y., in 1906, and received the degrees of bachelor of science in electrical engineering (1928) and master of science in electrical engineering (1930) at Worcester Polytechnic Institute. Following his graduation in 1928 he became research assistant to the late Doctor H. B. Smith (A'91, M'01, F'13, and past-president) at the Worcester Polytechnic Institute and pursued graduate studies at the same time. In 1930 he joined the central station engineering division of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., where he remained until he accepted a position as junior engineer in the distribution department of the Duquesne Light Company in 1934.

A. C. Marshall (A'14, F'29) vice president and general manager, Detroit (Mich.) Edison Company, recently was elected a trustee of the Edison Electric Institute. Mr. Marshall was born in 1872 at Middletown, Ohio, and graduated in electrical engineering from the University of Michigan in 1893. Following a brief period as electrical inspector for the Michigan Inspection Bureau, Detroit, he became field engineer for the Public Lighting Commission of the City of Detroit, and continued in that capacity until he was appointed chief engineer of the Rapid Railway System, Detroit.

He was associated briefly with the Detroit Edison Company during 1904–05; however, he left the employ of that company in 1905 to become general manager of the Port Huron (Mich.) Light and Power Company. In 1911 Mr. Marshall became assistant to the president of the Eastern Michigan Edison Company, a subsidiary of the Detroit Edison Company, and in 1912 he was appointed vice president of the Detroit company. He has been vice president and general manager since 1921. He served as a member of the committee on Institute policy during 1919–20.

C. A. Price (A'19) formerly assistant chief engineer, Canadian Westinghouse Company, Ltd., Hamilton, Ontario, has been appointed chief engineer. Mr. Price is a native (1875) of Crumlyne, Pa., and graduated in electrical engineering from Drexel Institute in 1898. After a preliminary training of 2 years, he was employed as a test engineer for the John A. Roebling Sons Company, Trenton, N. J., in 1900, and in 1901 he accepted a position with the Bell Telephone Company of Philadelphia, Pa. He entered the employ of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., in 1902, and after serving a 2 years' apprenticeship became designing engineer on a-c machinery. In 1906 Mr. Price was transferred to the Canadian Westinghouse Company in the same capacity, and in 1919 he was appointed assistant chief engineer. He was chairman of the Toronto Section of the Institute during 1934–35.

M. E. Leeds (A'01, F'26) president, The Leeds and Northrup Company, Philadelphia, Pa., recently was granted the honorary degree of doctor of engineering by the Polytechnic Institute of Brooklyn, N. Y. Mr. Leeds was born in 1869 at Philadelphia, and received the degree of bachelor of science at Haverford College in 1888; he also attended the University of Berlin, Germany, as a graduate student during 1892–93. In 1890 he entered the scientific instrument business with Queen and Company, Philadelphia, and remained in the services of that company until he established the firm of Morris E. Leeds and Company in 1899. The company was reorganized under the name of The Leeds and Northrup Company in 1903, with Mr. Leeds as president. He is the holder of numerous patents on electrical measuring apparatus and associated equipment, and is a member of Franklin Institute, American Association for the Advancement of Science, American Physical Society, American Society for Steel Treating, Academy of Natural Sciences, and American Society for Testing Materials.

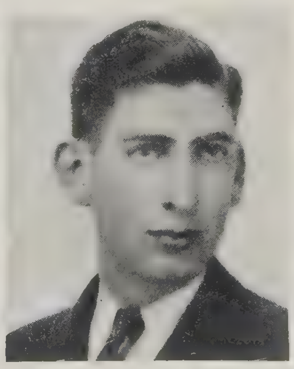
L. B. Chubbuck (A'18, M'26) formerly switching equipment engineer, Canadian Westinghouse Company, Ltd., Hamilton, Ontario, recently was appointed assistant chief engineer. Mr. Chubbuck was born in 1879 at Ottawa, Canada, and graduated in electrical engineering from the University of Toronto in 1900. In the same year he was employed by the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., as a switching equipment engineer. In 1909 he was transferred to the Canadian Westinghouse Company and placed in charge of switching equipment engineering. His service in that capacity has been uninterrupted. Mr. Chubbuck was chairman of the Institute's Toronto Section during 1925–26, and, in addition to being active in local Institute affairs, was a vice president during 1931–33; he has served on the Institute's committees on protective devices (1922–25) and safety codes (1931–33).

Samuel Ferguson (A'02) chairman of the board of directors, Hartford (Conn.) Electric Light Company, recently received the honorary degree of doctor of engineering from Rensselaer Polytechnic Institute. Mr. Ferguson was born in 1874, at Exeter, N. H., and received the degree of bachelor of science at Trinity College in 1896. In 1899 he received the degrees of electrical engineer and master of arts at Columbia University, and in the same year entered the employ of the General Electric Company Schenectady, N. Y., as a test engineer. In 1912 he was engaged by the Hartford Electric Light Company, and has been connected with that company continuously.

K. W. Jarvis (A'25, M'34) recently was appointed vice president of the Norwalk Engineering Corporation, South Norwalk, Conn. Mr. Jarvis is a native (1901) of Mansfield, Ohio, and a 1923 electrical engineering graduate of Ohio State University. After serving as student engineer for the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., he became actively identified with the radio industry. He has been connected with several radio receiver manufacturing companies, and became director of engineering of the Zenith Radio Corporation, Chicago, Ill., in 1932.

C. A. PRICE

L. B. CHUBBUCK



P. H. ODESSEY

F. W. Bliss (A'30) New England district manager, sales development department, General Electric Company, Boston, Mass., recently was elected president of the Engineering Societies of New England. Mr. Bliss was born at Cambridge, Mass., in 1883, and attended the Westerleigh Collegiate Institute. Following a brief training in the electrical contracting business, he was engaged by the International Mercantile Marine Company, New York, N. Y., in 1905, and in 1910 he became industrial illuminating engineer for the Edison Lamp Works, Providence, R. I. He has been connected with the General Electric Company in his present capacity since 1928.

E. S. Webster (A'91, M'07, and member for life) president, Stone and Webster, Inc., Boston, Mass., recently received the honorary degree of doctor of laws at Northeastern University. Mr. Webster was born in 1867 at Boston, and graduated in electrical engineering from the Massachusetts Institute of Technology in 1888. With C. A. Stone (A'91, M'07, and member for life) he formed the consulting engineering firm of Stone and Webster, Inc., in 1889, and has been an active member of the firm since that date.

J. H. Hunt (A'07, M'13) patent section, General Motors Corporation, Detroit, Mich., recently was elected president of the Engineering Society of Detroit. He has been active in establishing the society, and was selected as one of the initial board of directors of that organization. A brief biographical sketch of Mr. Hunt appeared in Electrical Engineering for May 1936, page 563.

P. H. Odessey (Enrolled Student) graduate student, Polytechnic Institute of Brooklyn, N. Y., has been awarded the 1935 A.I.E.E. prize for Branch paper for his paper "A Direct Current Controlled Transformer Voltage Regulator." Mr. Odessey is a native (1912) of Brooklyn, and received the degree of bachelor of electrical engineering at the Polytechnic Institute of Brooklyn in 1935. He is a member of Tau Beta Pi.

H. C. Blackwell (A'09) president, Union Gas and Electric Company, Cincinnati, Ohio, recently was elected a director of the Columbia Gas and Electric Corporation. Mr. Blackwell has been identified with public utility work throughout his entire technical career, and has been connected with the Union Gas and Electric Company since 1925.

W. C. Rudd (A'34) meter tester, New York (N. Y.) Edison Company, has been awarded one of the 3 James H. McGraw prizes of the Edison Electric Institute for "a meritorious paper on an engineering or technical subject relating to the electric

light and power industry." Mr. Rudd is an electrical engineering graduate of Rensselaer Polytechnic Institute (1933), and has been connected with the New York Edison Company since his graduation.

J. E. Hobson ('36) instructor in mathematics, Earlham College, has accepted a position as instructor on the electrical engineering staff of the Armour Institute of Technology. Mr. Hobson is co-author of a paper "The Sparkless Sphere Gap Voltmeter," published in Electrical Engineering for June 1936, p. 651–6.

Thomas Spooner (A'12, F'29) manager, general division, research laboratories, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been elected chairman of the American Society for Testing Materials committee A-6 on magnetic properties for the period 1936–37. He has been a member of the Institute's committee on research since 1929, and is the author of many papers on magnetics.

Vannevar Bush (A'15, F'24), Lamme Medalist '35) vice president, Massachusetts Institute of Technology, Cambridge, recently was elected chairman of the division of engineering and industrial research of the National Research Council. A biographical sketch of Doctor Bush was given in Electrical Engineering for March 1936, page 313.

R. J. Cobban (A'26, M'33) sales engineer, Westinghouse Electric and Manufacturing Company, San Francisco, Calif., recently won the 1936 first prize of the Pacific Coast Electrical Association for a paper written as a solution to the problem "How Can the Cost of Electric Distribution Be Lowered, Giving Due Consideration to Adequate Service and Regulation?"

H. F. Rost (A'12, M'29) chief, long lines department, Empresa de Telefonos Ericsson, Mexico D. F., Mexico, has retired from active business, and will undertake private research work in Sweden. Mr. Rost has been associated with the Empresa de Telefonos Ericsson since 1910.

O. H. Caldwell (A'13, M'22) editor of *Radio Today*, past chairman of the New York Section, has taken office (June 1) as president of the New York Amateur Astronomers Association of the American Museum of Natural History, New York, N. Y.

G. V. Harrap (A'34) formerly control room engineer, North-Eastern Electric Supply Company, Ltd., Newcastle-on-Tyne, England, recently accepted an appointment as assistant charge engineer in the power station of the Hull (England) Corporation, Electricity Department.

M. E. Noyes (A'20, M'30) electrical sales engineer, Aluminum Company of America, Pittsburgh, Pa., has been appointed chairman of the American Standards Association committee on aluminum, and chairman of the A.I.E.E. delegation on that committee.

I. M. Ellestad (A'24) now is transmission engineer for the Northwestern Bell Telephone Company, Omaha, Neb. Mr. Ellestad is an electrical engineering graduate (1922) of the University of Minnesota, and has previously been employed by several telephone companies in Minnesota and Nebraska.

Edward Woodbury (A'05, M'13) formerly superintendent of electrical construction and operations, California Pacific International Exposition, San Diego, recently accepted a position as associate electrical engineer for the Tennessee Valley Authority, Knoxville, Tenn.

G. A. Bouvier (M'29) formerly engineer of machining processes, Western Electric Company, Inc., Chicago, Ill., recently accepted a position as director of engineering for the Minneapolis Honeywell Regulator Company, Minneapolis, Minn.

H. D. Rohman (M'19) formerly sales representative, American Locomotive Company, New York, N. Y., now is South African resident engineer for the consulting firm of J. Stone and Company, Ltd., Johannesburg.

L. W. Eighmy, Jr. (A'36) formerly assistant to the general superintendent, Buffalo (N. Y.) General Electric Company, recently accepted a position as sales engineer for the Kerite Insulated Wire and Cable Company, Inc., New York, N. Y.

G. W. Hart (A'31) formerly commercial engineer, New York and Queens Electric Light and Power Company, Long Island City., N. Y. has resigned to enter the commercial department of Ebasco Services, Inc., New York, N. Y.

G. C. Harvey (A'33) formerly engineer in the factory methods and cost reduction department, General Electric Company, Schenectady, N. Y., has been transferred to the small motor section at Fort Wayne, Ind., as motor designer.

L. F. Sampio (A'29) formerly chief engineer, electrification department, Companhia Paulista de Estradas de Ferro, Sao Paulo, Brazil, now is connected with the Metropolitan-Vickers Electrical Export Company, Ltd., Rio de Janeiro, Brazil.

C. J. Nevitt (A'33) formerly employed by the water department of the City of San Diego, Calif., recently accepted a position as electrical estimator for the San Diego (Calif.) Consolidated Gas and Electric Company.

Cleveland Hopkins (A'34) formerly employed by the Certain-teed Products Corporation, Richmond, Calif., has accepted a position with the Owens-Illinois Pacific Coast Company, San Francisco, Calif.

J. B. Snediker (M'36) formerly division transmission engineer, American Telephone and Telegraph Company, New York, N. Y., now is district plant superintendent of the Transpacific Communication Company, Ltd., San Francisco, Calif.

L. A. Eggleston (A'32) formerly conservation engineer, National Aniline and Chemical Company, Buffalo, N. Y., now is employed as industrial engineer for E. I. du Pont de Nemours and Company, Deepwater, N. J.

W. W. Watkins (A'36) formerly substation operator, Jones and Laughlin Steel Corporation, Pittsburgh, Pa., now is employed by the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., as an electrical tester.

Maurice Prevost (A'21) formerly manager, Industrial Construction Company, Ltd., Montreal, Quebec, recently was appointed a member of the electrical engineering staff of the Quebec Electricity Commission, with offices at Montreal.

C. R. Delagrange (A'30) assistant development engineer, Firestone Cotton Mills, New Bedford, Mass., has been transferred to the engineering department of the Firestone Tire and Rubber Company, Akron, Ohio.

Leonard Beaumont (A'26) former relay engineer, Shanghai (China) Power Company, now is employed by the signal and telegraph department of the London and Northeastern Railway Company, York, England.

G. L. Guinther (A'34) formerly with the Niagara, Lockport, and Olean Power Company, Avon, N. Y., now is employed in the cycle change-over department of the Niagara Hudson Power Company, Batavia, N. Y.

M. F. Beall (A'32) has resigned his position in the Diesel engineering department, Timken Roller Bearing Company, Canton, Ohio, and now is employed by the U.S. Bureau of Reclamation, Denver, Colo.

D. P. Fullerton (A'29) recording engineer, Electrical Research Products, Inc., Los Angeles, Calif., has been transferred to the New York, N. Y., offices of that Company.

H. R. Nelson (A'33) formerly inspector, Waukesha (Wis.) Motor Company, recently accepted a position as assistant switchboard operator for the Tennessee Valley Authority, Wilson Dam, Ala.

C. F. Prideaux (A'33) formerly maintenance engineer, Municipal Light and Water Plant, Adrian, Minn., recently accepted a position with the Northwestern Public Service Company, Huron, S. D.

M. H. Masters (A'35) formerly of the Ford Motor Company, Somerville, Mass., has accepted a position as clerk in the load dispatching office of the Edison Electric Illuminating Company of Boston, Mass.

Norman Thornton (M'35) formerly deputy chief engineer, electricity branch, Public Works Department of the Punjab Government, Lahore, India, recently was appointed executive engineer.

R. H. Barclay (A'14, F'28) formerly chief of the analysis and reports division of the Federal Power Commission, has been appointed regional director, with offices at New York, N. Y.

H. F. Brinckerhoff (A'24) sales engineer, Westinghouse Electric and Manufacturing Co., Washington, D. C., has been transferred to the Philadelphia (Pa.) offices of that company.

G. L. Quigley (A'32) formerly assistant manager, Commodore Hotel, Wichita, Kan., recently joined the engineering staff of the Coleman Lamp and Stove Company, Wichita.

E. J. Shimek (A'31) former instructor in electrical engineering, The Rice Institute, Houston, Texas, recently accepted a position as electrical engineer with Seismic Explorations, Inc., Houston.

Clarence Auty (A'18, M'26) formerly assistant electrical engineer, Charles H. Tenney and Company, Boston, Mass., now is with the New England Power Service Company, Malden, Mass.

Haskell Roeser (A'32) formerly engineer and estimator for Biggs and Kirchner, Inc., Washington, D. C., now is assistant engineer for the Potomac Electric Power Company, Washington.

R. L. Ringer, Jr. (A'35) formerly engineering assistant, Wilson Welder and Metals Company, North Bergen, N. J., now is employed by the Agfa Ansco Corporation, Johnson City, N. Y.

H. P. Miller (A'17) formerly with the International Standard Electric Corporation, New York, N. Y., has been transferred to the Compania Standard Electric Argentina, Buenos Aires.

G. E. Van Vessem (A'36) formerly employed by the Western Electric Company, West Haven, Conn., now is connected with the firm of H. L. Van Duzer, Warwick, N. Y.

F. M. Potter (A'35) formerly assistant switchgear test foreman, General Electric Company, Schenectady, N. Y., has been transferred to the motor engineering department, at the Lynn, Mass., works.

C. I. Shields (A'34) formerly power plant operator, Western Colorado Power Company, Durango, has been transferred to the Silverton, Colo., station of that company as a load dispatcher.

R. L. Johnson (A'34) former student engineer, Municipal Electric Light Plant, Hagerstown, Md., now is employed in the power department of the Potomac Edison Company, Hagerstown.

H. G. Tasker (A'26, M'34) formerly chief engineer, United Research Corporation Burbank, Calif., recently accepted a position with the Universal Pictures Corporation, Universal City, Calif.

R. B. Shores (A'35) formerly student engineer, General Electric Company, Schenectady, N. Y., has been transferred to the Philadelphia, Pa., works as requisition engineer in the switchgear department.

A. J. Cunningham (A'35) electrical engineer, Metropolitan-Vickers Electrical Export Company, Rio de Janeiro, Brazil, has been transferred to the Manchester, England, offices of that company.

T. B. Linklater (A'35) former radio inspector, Ontario (Canada) Forestry Branch Radio, Toronto, recently accepted a position as radio operator for the Canadian National Telegraphs, Amos, Quebec.

N. R. Gibson (M'32) vice president, Buffalo, Niagara, and Eastern Power Corporation, Buffalo, N. Y., has been appointed a member of the New York State Board of Engineering Examiners.

E. L. Green, Jr. (A'36) former tester, The New York (N. Y.) Edison Company, recently accepted a position in the engineering department of the Eastman Kodak Company, Rochester, N. Y.

B. H. Ormson (A'22) formerly chief electrician, Little Ben Mining Company, Landusky, Mont., now holds a similar position with the Ruby Gulch Mining Company, Zortman, Mont.

E. O. Martinson (A'33) formerly junior engineer, Mason - Walsh - Atkinson - Kier Company, Mason City, Wash., now is junior mechanical engineer for the Tennessee Valley Authority, Knoxville, Tenn.

T. D. Oswald (A'34) junior technical assistant, Newcastle and District Electric Lighting Company, Newcastle-on-Tyne, England, has been appointed technical assistant.

E. S. Atkinson (M'31) formerly sales engineer, H. B. Sherman Manufacturing Company, Battle Creek, Mich., now is with the Penn-Union Electric Corporation, Erie, Pa.

H. H. Fry (A'34) former assistant to the efficiency engineer, Associated Gas and Electric Company, Patchogue, N. Y., now is sales engineer for the Morse Chain Company, Philadelphia, Pa.

G. O. Eaton (A'18) formerly electrical engineer, Charles H. Tenney and Company, Boston, Mass., recently accepted a position as district engineer for the New England Power Company, Malden, Mass.

H. E. Mason (A'31) formerly an electrical engineer for The Okonite Company, Passaic, N. J., recently accepted a similar position with the Mason Silk Company, Winsted, Conn.

A. J. McLennan (A'32) formerly master mechanic, Shell Oil Company of Canada, Montreal, recently accepted a position as electrical engineer for the Narragansett Electric Company, Providence, R. I.

Nick Mars (A'36) former electrical engineer, P. R. Mallory Electric Manufacturing Company, Indianapolis, Ind., now is employed by the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

M. Van V. Hayes (A'35) operating supervisor, Tide Water Oil Company, Boston, Mass., has been transferred to the East Providence, R. I., branch in a similar position.

P. H. Maurer (A'33) formerly development engineer, Eclipse Machine Company, Elmira, N. Y., now is employed in the engineering department of the Hudson Motor Car Company, Detroit, Mich.

W. W. Kuyper (A'34) student engineer, General Electric Company, Schenectady, N. Y., has been transferred to the turbine generator department at the West Lynn, Mass., works.

N. H. Sauberman (A'35) formerly with the Gruen Engineering Company, Inc., Long Island City, N. Y., now is connected with Atlantic Heat and Power, Inc., New York, N. Y.

D. C. Hierath (A'35) formerly construction engineer, General Electric Company, Schenectady, N. Y., has been made field engineer in the New Haven, Conn., offices of that company.

G. S. Dring (A'21, M'32) formerly division plant superintendent, American Telephone and Telegraph Company, Denver, Colo., has been transferred to the Atlanta, Ga., offices in a similar capacity.

G. A. Brace (A'31) former patent examiner, U.S. Patent Office, Washington, D. C., recently accepted a postion as patent attorney for the Hoover Company, Chicago, Ill.

S. C. Greidanus (A'35) formerly assistant superintendent, Tung-Sol Lamp Works, Inc., Newark, N. J., has accepted a position as engineer for the H. A. Wilson Company, Newark.

W. J. Matthews (A'34) formerly electric meterman, Blackstone Valley Gas and Electric Company, Pawtucket, R. I., now is employed by the Virginia Electric and Power Company, Richmond.

Leo Dubinski (A'31) formerly electric substation operator, Pacific Gas and Electric Company, San Francisco, Calif., now is application examiner for the Tennessee Valley Authority, Knoxville, Tenn.

J. B. Hardie (A'36) formerly an electrical engineer, Reliance Electric and Engineering Company, Cleveland, Ohio, recently accepted a similar position with the A. G. Redmond Company, Flint, Mich.

R. H. Ross (M'25) formerly general plant supervisor, American Telephone and Telegraph Company, New York, N. Y., has been transferred to Philadelphia, Pa., as division plant superintendent.

G. L. King (A'36) electrical engineer, Oklahoma Gas and Electric Company, Oklahoma City, has been transferred to the Ardmore, Okla., offices of that company.

B. M. Cain (A'34) industrial consulting engineer, General Electric Company, Schenectady, N. Y., has been transferred to the Lynn (Mass.) works of that company.

R. C. Jackson (A'33) inspector, U.S. Engineer Office, Nebraska City, Nebr., has been transferred to the Omaha, Nebr., office in a similar capacity.

E. W. Macoy (A'33) electrical engineer, American Can Company, Cincinnati, Ohio, has been transferred to the Jersey City, N. J., offices of that company.

K. E. V. Hallar (A'31) formerly designer, Krangede A-B, Stockholm, Sweden, now is assistant operating engineer for the Husqvarna (Sweden) Vapenfabriks A-B.

P. E. Benner (A'28) former electrical engineer, General Electric Company, Schenectady, N. Y., now is operating engineer for the Georgia Power Company, Atlanta.

J. S. Ensor (A'26) associate engineer, corps of engineers, U.S. Army, Washington, D. C., has been transferred to the U.S. Engineer's Office at Tucumcari, N. M.

F. W. Lewis (A'33) formerly surveyman, U.S. Engineers Department, Detroit, Mich., now is employed by the Detroit Edison Company.

C. H. Anderson (M'34) formerly superintendent, Bradford (Pa.) Electric Company, now is with the Niagara, Lockport, and Ontario Power Company, Medina, N. Y.

L. J. Fritz (A'35) record supervisor, Ohio Bell Telephone Company, Toledo, has been transferred to the Dayton offices of that company.

E. R. Sine (A'32) assistant district engineer, General Cable Corporation, Chicago, Ill., has been transferred to the Rome, N. Y., offices of that company.

F. T. Roddy (A'35) operating engineer, Minnesota Utilities Company, Minneapolis, has been transferred to the Savanna, Illinois, offices of that company.

Obituary

George Carl Shaad (A'03, M'08, F'13) dean of the school of engineering and architecture, University of Kansas, Lawrence, died July 9, 1936. Professor Shaad was born May 5, 1878, at Stratford, N. Y., and received the degrees of bachelor of science in electrical engineering (1900) and electrical engineer (1905) at Pennsylvania State College. Following his graduation in 1900 he entered the testing department of the General Electric Company, Schenectady, N. Y., later transferring to the switchboard engineering department, where he remained until 1902. He was appointed instructor in electrical engineering at the University of Wisconsin in 1902, and taught in that institution until he was appointed assistant professor in the electrical engineering school of the Massachusetts Institute of Technology in 1906; in 1907 he was made associate professor of electrical engineering. When the school of electrical engineering was recognized as a department separate from the physics department at the University of Kansas, he accepted an appointment as professor of electrical engineering in 1909, and has remained in that position continuously. He acted as dean of the school of engineering and architecture, 1917–18, and was appointed permanently to that position in 1927. In addition to his regular teaching duties, Professor Shaad served as consulting engineer for several engineering companies. He was chairman of the Institute's Kansas City Section during 1920–23, and, in addition to being active in local Institute affairs, was a vice president, 1930–32, director, 1935–36, and a member of the committee on student Branches. He was a member of The American Society of Mechanical Engineers, Society for the Promotion of Engineering Education, Sigma XI, and Tau Beta Pi. Long active in Institute affairs, Dean Shaad had gone to Pasadena to attend the 52d Annual A.I.E.E. Summer Convention, but was stricken ill en route and committed to the Huntington Memorial Hospital upon arrival.

William Fullerton White (A'90, M'98, and member for life) president, Nassau Securities Corporation, New York, N. Y., died in May 1936. Mr. White was born February 28, 1867, at Milroy, Pa., and graduated in electrical engineering from Pennsylvania State College. Following his graduation, he became engaged in electrical contracting and construction work as a member of the Western Engineering Company, Lincoln, Neb., and in 1890 he moved to Omaha, Neb., as district manager of the Edison General Electric Company. When the General Electric Company was formed, Mr. White continued to manage the Omaha offices of that company. In 1893 he was placed in charge of all exhibits of the General Electric Company at the Columbian Exposition, Chicago, and in 1894 he was transferred to Schenectady, N. Y., as engineer on a committee for the administration of local branches of the General Electric Company. In 1895 he returned to Omaha as general manager of the New Omaha Thomson-Houston Electric Light Company. and held that position until he became electrical engineer for the North American Company, New York, N. Y., in 1902. In 1908 he became president of the Aquacate Mines, New York, and in 1911, president of the White Investing Company, New York. Mr. White became president of Nassau Securities Corporation in 1928.

Albert Sutton Richey (A'97, M'04, F'12, and member for life) professor of electric railway engineering, Worcester (Mass.) Polytechnic Institute, died June 24, 1936. Professor Richey was born at Muncie, Ind., April 10, 1874, and received the degrees of bachelor of science in electrical engineering (1894) and electrical engineer (1908) at Purdue University. In 1896 he was employed as chief electrician of the Citizens Street Railway Company, Muncie, Ind.; he became electrical engineer (1899) and chief engineer (1903) of the Indiana Union Traction Company, before being appointed to the faculty of Worcester Polytechnic Institute as professor of electric railway engineering in 1905. In addition to his teaching duties, he served as consulting engineer for several railway companies and wrote a widely accepted electric railway handbook. Professor Richey served on the Institute's committee on transportation, 1914–17 and 1929–31. He was a member of the American Transit Association.

William Grosvenor Ely, Jr. (A'93 and member for life) retired manager of the contract service department, General Electric Company, Schenectady, N. Y., died in June 1936. Mr. Ely joined the General Electric Company in the testing department in 1892, following his graduation from Brown and Cornell universities. In 1896 he became assistant to the superintendent of the construction department, and in 1898, superintendent of that department. He was manager of the contract service department from 1922 until his retirement in 1927.

Earle Lamar Tyler (A'36) radio engineer, National Broadcasting Company, New York, N. Y., drowned in Lake Erie near Cleveland, Ohio, June 15, 1936. Mr. Tyler was born July 10, 1907, at Broxton, Ga., and graduated from Clemson Agricultural and Mechanical College in 1930. Immediately following his graduation he joined the engineering staff of the National Broadcasting Company as construction engineer. He held that position for one year; in 1931 he was made radio design engineer, and had been retained continuously in that capacity.

Membership

Recommended for Transfer

The board of examiners, at its meeting on July 22, 1936, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Porter, Lawrence C., illuminating engineer, General Electric Co., Cleveland, O.
Ross, James H., chief electrician, Freeport Sulphur Co., New Orleans, La.
Shepard, Robert B., electrical engineer, Underwriters' Laboratories, New York, N. Y.

3 to Grade of Fellow

To Grade of Member

Alford, E. L., member of technical staff, Bell Telephone Laboratories, Inc., New York, N. Y.
Anderson, H. R., assistant electrical engineer, U.S. Engineers, War Department, Fort Peck, Mont.
Billica, H. J., sales engineer, Indiana Steel and Wire Co., Muncie, Ind.
Bowld, William F., manager, pulp department, Buckeye Cotton Oil Co., Memphis, Tenn.
Champlin, E. A., electrical engineer, U.S. Navy Yard, Public Works Division, Boston, Mass.
Commander, S. C., sales engineer, Southern Joslyn Co., Inc., Memphis, Tenn.
Drushel, R. W., distribution engineer, The Ohio Public Service Co., Alliance, O.
Godsey, F. W., Jr., chief electrical engineer, Sprague Specialties Co., North Adams, Mass.
Hammond, S., assistant engineer, Public Service Electric and Gas Co., Newark, N. J.
Holbeck, J. I., relay engineer, Minnesota Power and Light Co., Duluth, Minn.
Lorraine, R. G., electrical engineer, General Electric Co., Schenectady, N. Y.
McCauley, A. D., district plant engineer, American Telephone and Telegraph Co., Minneapolis, Minn.
Oser, W. K., member of technical staff, Bell Telephone Laboratories, Inc., New York, N. Y.
Pollock, S. H., regulation engineer, Kansas City Power and Light Co., Kansas City, Mo.
Richey, A. L., cable apparatus engineer, Bell Telephone Laboratories, Inc., New York, N. Y.
mith, M. W., manager of engineering, Westinghouse Electric and Manufacturing Co., East Pittsburgh, Pa.
Teare, B. R., assistant professor of electrical engineering, Yale University, New Haven, Conn.
Tilles, A., instructor in electrical engineering, University of California, Berkeley, Calif.
Tipton, E. W., electrical engineering, Westinghouse Electric and Manufacturing Co., Sharon, Pa.
Treanor, E. D., executive engineer, distribution transformer dept., General Electric Co., Pittsfield, Mass.
Whipple, R. R., assistant professor of electrical engineering, University of Iowa, Iowa City.
Wild, E., load dispatcher, Commonwealth Edison Co., Chicago, Ill.
Zucker, M., engineering division, Detroit Edison Co., Detroit, Mich.

23 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before August 31, 1936, or Sept. 30, 1936, if the applicant resides outside of the United States or Canada.

Apple, O. L., The A. F. Preeter Electric Co., Toledo, Ohio.
Beers, E. R., E. R. Beers Electric Co., Bloomsburg, Pa.
Boyce, R. P., South Linden St., Hempstead Gardens, N. Y.
Butts, C. A., Youngstown Sheet and Tube Co., East Chicago, Ill.
Clark, W. H. (Member), Jersey Central Power and Light Co., Asbury Park, N. J.
Currie, E. B., General Electric Co., Rochester, N. Y.
Elble, C. W., Union Gas and Electric Co., Cincinnati, Ohio.
Evans, C. W., W. R. C. Smith Publishing Co., Atlanta, Ga.
Frend, J. J. (Member), c/o A. J. Bassett, 198 Broadway, New York, N. Y.
Fuller, A. C. (Member), General Cable Corp., White Plains, N. Y.
Glasby, J. B. (Member), Atlantic Refining Co., Philadelphia, Pa.
Grooms, W. N., Mine and Smelter Supply Co., Salt Lake City, Utah.
Huggler, G. C., 25 Park St., Montclair, N. J.
Koopman, R. J. W., Michigan College of Mining and Techonology, Houghton, Mich.
Marks, G. F., Brooklyn Edison Co., Inc., New York, N. Y.
McAffe-ty, H. G., Joslyn Company of California, Los Angeles.
Olive, J. M., Memphis Power and Light Co., Madison, Tenn.
Scott, E. M., Southern California Edison Co., Ltd., Los Angeles, Calif.
Smith, L. M., Washington Water Power Co., Spokane, Wash.
Sunde, E. D., Bell Telephone Laboratories, Inc., New York, N. Y.
Wheeler, F. K. B., U.S.S. Minneapolis, San Pedro, Calif.
Walthour, F. D. (Member), Ohio Bell Telephone Co., Cleveland, Ohio.
White, A. B., Kansas Gas and Electric Co., Wichita.
Widdifield, I. S., Norton Co., Chippawa, Ontario, Canada.
24 Domestic

Foreign

Facey, E. R. (Member), Central Espana, Perico, Matanzas, Cuba.
Faxon, H. C. (Member), The Borneo Company, Ltd., Singapore, Straits Settlements.
Gardner, J. D., Cerro de Pasco Copper Corp., Peru.
Haigh, R. W. (Member), Johnson and Phillips, Ltd., Charlton, S. E. 7, England.
Luzier, P. H., Public Utilities Honduras Corp., San Pedor Sula, Honduras, C. A.
Pradhan, H. R., 12A, Apollo Street, Fort, Bombay, India.
Rashduni, H. D., Iraq Petroleum Co., Ltd., Haditha, Iraq.
Robinson, D. H. (Member), Electricity Branch, Public Works Department, Amritsar, India.
Taggart, J. E. (Member), Punjab Public Works Department, Lahore, India.
Yatskin, M. C., 53 Cumberland Road, Kowloon Tong, Hong Kong, China.
10 Foreign

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the addresses as they now appear on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Koch, Joseph Stanly, 11 Howe Ave., New Rochelle, N. Y.
Bukley, E. J., Malaja-Dmitrovka D. 8 Kv. 38, Moscow, U.S.S.R.
Burns, Arthur E., 1958 E. 29th St., Brooklyn, N. Y.
Collins, Ogie B., Minimum, Mo.
Eiler, E. E., 101 Brookline Court, Upper Darby, Pa.
Jones, Harry Kenneth, 5511 Kenmore Ave., Chicago, Ill.
Koch, Joseph Stanley, 11 Howe Ave., New Rochelle, N. Y.
Luther, Herbert A., 50 Atwood Ave., Johnston, R. I.
Megeath, S. A., Jr., 14 North Ave., Elizabeth, N. J.
Merrill, Warren C., 208 W. 8th St., Los Angeles, Calif.
Millheisler, Charles A., 1417 Catalpa Ave., Chicago, Ill.
Miyota, Nath S., 916½ Howell St., Seattle, Wash.
Pollastro, John B., Helper, Utah.
Ridenhour, W. L., 216 Vance St., Chapel Hill, N. C.
Walstra, W. G., Y. M. C. A., Boise, Idaho.
Willson, William H., Jr., 1720—2nd Ave., Cedar Rapids, Iowa.
Wong, Harry Y. L., 771 Broadway, West New York, N. J.
16 Addresses Wanted

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently, are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

Great Britain, Dept. of Scientific and Industrial Research. ILLUMINATION RESEARCH Tech. Paper No. 18, TRANSMISSION of LIGHT THROUGH WINDOW GLASSES. Lond., H. M. S. O., 1936. 18 p., illus., 10x6 in., paper, 9d. (Obtainable from British Library of Information, N. Y., $0.30.) Gives transmission factors of 49 kinds of glass measured under different distributions of incident light and measurements of transmission loss owing to gradual accumulation of dirt.

LEGAL and ETHICAL PHASES of ENGINEERING. By C. F. Harding and D. T. Canfield. N. Y. and Lond., McGraw-Hill Book Co., 1936. 432 p., illus., 9x6 in., cloth, $4.00. Discusses the more important legal and ethical principles that must govern the business relations of the young engineer with other engineers and the public. Contains discussions of the law of contracts, specifications and estimates, the expert witness, patents, the laws of agency and sales, public relations, and professional ethics.

JAMES WATT, Craftsman and Engineer. By H. W. Dickinson. Cambridge, England, Univ. Press, N. Y., Macmillan Co., 1936. 207 p., illus., 10x6 in., cloth, $4.00. Intended for the general reader who is more interested in the life and work of Watt than in the development of the steam engine.

FORTSCHRITTE des CHEMISCHEN APPARATEWESENS: ELEKTRISCHE ÖFEN. Lieferungen 1, 4, 5, and 6. Ed. by A. Bräuer, J. Reitstötter and H. Alterthum. Leipzig, Akademische Verlagsgesellschaft, 1934–1936. (28 rm. each; 22 rm. each on subscription), diagrs., 11x8 in., paper. Provides an account of the development of the electric furnace. Describes outstanding improvements, and contains abstracts of all German patents. Electrical and structural developments and the uses of electric furnaces are discussed.

HUTCHINSON'S TECHNICAL and SCIENTIFIC ENCYCLOPEDIA. 4 v. Ed. by C. F. Tweney and I. P. Shirshov. N. Y., Macmillan Co., 1936. 2468 p., illus., 10x7 in., cloth, $25.00. Meets the need of students and technical workers for quick reference on a great variety of subjects. Terms and processes in pure and applied science, engineering, manufacturing and the skilled trades are defined and described.

DYNAMICS of RIGID BODIES. By W. D. MacMillan. N. Y. and Lond., McGraw-Hill Book Co., 1936. 478 p., illus., 9x6 in., cloth, $6.00. Provides a thorough course in the theory of the subject, suited to the needs of university students who have an advanced training in mathematics.

DESCRIPTIVE GEOMETRY. By C. H. Schumann. 2 ed. N. Y., D. Van Nostrand Co., 1936. 336 p., illus., 10x6 in., $2.75, cloth. An elementary text. The subject is presented from the student's viewpoint, and problems are described in detail.

WÄRMETECHNISCHE ARBEITMAPPE, gesammelte Arbeitblätter aus den letzten Jahrgängen von "Archiv für Wärmewirtschaft und Dampfkesselwesen." Ergänzungslieferung. Berlin, VDI-Verlag, 44 pp., charts, 12x9 in., paper, 4.40 rm. A supplementary collection of 44 new charts relative to fuels, feed water, firing, steam turbines, internal-combustion engines, heating and steam distribution.

ADVANCED LABORATORY PRACTICE in ELECTRICITY and MAGNETISM. By E. M. Terry and H. B. Wahlin. 3 ed. N. Y. and Lond., McGraw-Hill Book Co., 1936. 318 p., illus., 9x6 in., cloth, $3.00. A course for students who have at their disposal only one year for the study of electricity and magnetism in addition to the work covered in a course in general physics.

Les SYSTÈMES OSCILLANTS. By J. Granier. Paris, Dunod, 1936. 215 p., illus., 10x6 in., cloth, 55 frs.; paper, 45 frs. Facilitates the study of oscillating systems by providing a survey of the oscillatory phenomena of electricity, optics, and mechanics.

KEMPE'S ENGINEER'S YEAR BOOK. 42nd annual issue, revised. Lond., Morgan Bros., 1936. 2664 p., illus., 7x5 in., lea., 31s. 6d. A new section on acoustics has been added. Covers a wide field, and is adapted to the needs of the practicing engineer.

GLANCES at INDUSTRIAL RESEARCH during Walks and Talks in Mellon Institute. By E. R. Weidlein and W. A. Hamor. N. Y., Reinhold Pub. Corp., 1936. 246 p., illus., 8x5 in., cloth, $2.75. Explains to the business man how industrial research is conducted at the Mellon Institute.

FUNKTECHNIK. I: Allgemeine Einführung mit besonderer Berücksichtigung des Rundfunks. By I. Herrmann. Berlin and Leipzig, Walter de Gruyter, 1936. 144 p., illus., 6x4 in., cloth, 1.62 rm. A concise statement of the fundamental principles of radio, and includes chapters on the electric circuit, electromagnetic waves, vacuum tubes, and transmitting and receiving.

Die KORROSION des EISENS und SEINER LEGIERUNGEN. Ed. by G. Masing, E. H. Schulz, C. Carius, K. Daeves, E. Houdremont, H. Schottky. Leipzig, S. Hirzel, 1936. 560 p., illus., 10x7 in., paper, 39 rm. A review of the theoretical knowledge of the corrosion of metals.

GEOMETRICAL DRAWING. By I. C. S. Staff. Scranton, Pa., International Textbook Co., 1935. Illus., 8x5 in., lea., $1.50. A text on the elements of geometrical and projection drawing designed for home study.

HEAT for Advanced Students. By the late E. Edser. Revised ed. by N. M. Bligh. Lond. and N. Y., Macmillan Co. 1936. 487 p., illus., 7x5 in., cloth, $1.75. Intended to provide a comprehensive account of the theoretical and experimental aspects of the subject without the use of higher mathematics.

MINERALOGY, an INTRODUCTION to the STUDY of MINERALS and CRYSTALS. By E. H. Kraus, W. F. Hunt and L. S. Ramsdell. 3 ed. N. Y. and Lond., McGraw-Hill Book Co., 1936. 638 p., illus., 9x6 in., cloth, $5.00. A simple presentation for use by beginners. Contains chapters on physical properties, the polarizing microscope, crystal structure and X ray analysis.

TECHNICAL DRAWING. By F. E. Giesecke, A. Mitchell and H. C. Spencer. N. Y., Macmillan Co., 1936. 546 p., illus., 10x6 in., cloth, $3.00. Intended as a class text and reference book.

Industrial Notes

Ford Adds Power Distribution Equipment.—With consumption of electric power by the Rouge plant of the Ford Motor Co. at an all-time peak, work has begun on an addition to the power plant to house new distribution equipment. The structure together with equipment will cost approximately $420,000. The distribution equipment to be installed this year will provide 12 additional circuits intended to meet the requirements of immediate future needs. Provision has been made for the installation of 12 additional circuits at a later date, giving the power house a total of 66 main power lines to the Rouge plant. The new circuits will give the power plant distribution equipment capable of handling a load of 265,000 kilowatts. The ultimate capacity of the power plant will be 345,000 kilowatts. The present generating equipment has a peak capacity of 265,000 kilowatts, including two 110,000 kw turbogenerators. One of these large units began operation only the latter part of July, when several smaller machines were withdrawn from service.

American Lava Corp. in New Plant.—The American Lava Corporation, Chattanooga, Tenn., has completed the construction of its new steatite ceramics plant and laboratory and it is now in operation, producing an average of one million pieces daily. The new building has triple the capacity of the old plant according to President Paul J. Kruesi, who has been connected with the company for more than a third of a century.

Emerson Electric Expands.—To provide additional space for manufacturing operations, the Emerson Electric Mfg. Co., St. Louis, Mo., recently leased approximately 43,000 square ft of floor space for warehouse purposes, located in a modern two-story building at Chouteau and Theres Aves. A further expansion is now under way. The general offices of the company are to be moved to a two-story building located at 19th and Washington Aves., with approximately 34,000 square ft of floor space. The space now devoted to office use at 2012 Washington Ave. will be absorbed by the manufacturing department.

Westinghouse Acquires New Plant.—Due to the necessity for expanding the production facilities of its Springfield, Mass., works in merchandising lines, particularly refrigeration and air conditioning units, the Westinghouse Electric & Mfg. Co. announces that it will transfer the manufacture of small motors now produced at its Springfield plant to Lima, O. A plant has been acquired at that point with approximately 300,000 square feet of floor space, and the installation of machinery is under way. It is expected that motor production may be started in the new factory by the first of the year. All Westinghouse motors for home appliance equipment will be produced in the new factory.

New Distribution Transformer.—The Allis-Chalmers Mfg. Co. has developed a new line of distribution transformers for rural service, characterized by exceptionally low copper loss and low inherent reactance. These transformers are furnished in the various commercial voltages in sizes from $1^1/_2$ to 10 kva, inclusive. They form an addition to the company's existing line of rural type transformers and supplement its conventional lines of distribution types. The new transformers can be provided with arrangements for directly bolting to the pole or conventional hanger hooks can be supplied. They are made either with one or two primary bushings and include provisions for mounting surge diverters.

Trade Literature

Transformers.—Bulletin 181, Power Transformers, 70 pp. Describes the assembly, construction features, installations, accessories, etc., of all types of single and three-phase transformers of ratings of 501 kva and above. Wagner Electric Corp., 6400 Plymouth Ave., St. Louis, Mo.

Bus Conductors.—Bulletin, "Anaconda Copper Bus Conductors." In addition to considerable performance data on various bus arrangements the booklet provides a new and interesting illustration of the phenomenon which is explained briefly and concisely. Anaconda Wire and Cable Co., 25 Broadway, New York.

Transmission Line Potential Indicator.—Catalog No. 11, 4 pp. Describes a new device, consisting of a coupler unit and instrument, known as the "Hipot Potential Indicator," for indicating whether a high voltage line is energized or dead and the relative phase position for synchronizing two or more lines. Roller-Smith Co., 233 Broadway, New York.

Oil Immersed Float Switch.—Bulletin 3643. Describes a new oil immersed float switch for use in hazardous locations. This switch is completely oil immersed and the enclosing case is weather-resisting and dust-tight. It operates to maintain low or high liquid level, incorporates quick acting make-and-break mechanism, easily accessible, and is explosion-proof. The Rowan Controller Co., Baltimore, Md.

Resistors.—Loose-leaf bulletins. Describe fixed, adjustable, and automatic resistors or ballasts. The data includes complete electrical and mechanical characteristics of each type of resistor. The line embraces flexible, strip, and voltage dropping resistors, volume controls of the wire-wound and composition-element types, and a variety of ballasts for automatic voltage regulation. Clarostat Mfg. Co., Inc., 285 North 6th St., Brooklyn, N. Y.

Aerial Cables.—GEA-2408, 8 pp. Describes type SS, self-supporting aerial cable for use on urban, suburban, and rural circuits, for both primary and secondary distribution. The construction consists of a solid or stranded central conductor surrounded by a wall of insulation of proved electrical properties and resistance to moisture. Over this insulation is placed a covering of alternate strands of round, galvanized-steel wire interlocked with special electric conducting wires. General Electric Co., Schenectady, N. Y.

Transformers.—Bulletin 180, Distribution Transformers, 102 pp. Discusses the characteristics, insulation, core and coil construction, tank design, accessories, testing, etc., of the following kinds of transformers of ratings of 500 kva and below: (1) Five types of single-phase, oil-filled, self-cooled; (2) Three-phase; (3) Subway; (4) Stud-bushing type; (5) Surge-protected distribution; (6) Rural line; (7) Instrument; (8) Air-cooled (general purpose and auto transformers). Wagner Electric Corp., 6400 Plymouth Ave., St. Louis, Mo.

Resistance Instruments.—Catalog. Describes precision type resistance instruments and allied products of special interest to manufacturers of sound transmission equipment, broadcast stations, and laboratories of all kinds. The products include volume control attenuators, attenuators for measurements, L, T, and H pads, fixed loss pads, taper pads, voltage dividers, faders, output controls, speaker pads, precision attenuators for laboratory use, gain sets, transmission measuring sets, volume indicators, decade resistance boxes, R. F. precision laboratory resistors, decade potentiometers, etc. Tech Laboratories, 703 Newark Ave., Jersey City, N. J.

Voltage Regulators.—A connected series of bulletins describing voltage regulation methods and apparatus for every vital point on a power system at low first cost. Bulletin numbers and titles follow: GEA-2053A, 12 pp. (Introductory) The 8-Point Plan for Profitable Voltage Regulation; GEA-2029A, 8 pp., Generator-Voltage Regulators; GEA-2054A, 8 pp., Station-Type Induction Regulators; GEA-2018B, 4 pp., Branch-Feeder Induction Regulators; GEA-2038B, 8 pp., Branch-Feeder Step Regulators; GEA-2036B, 8 pp., Branch-Feeder Boosters; GEA-1577C, 12 pp., Station-Type Step Regulators; GEA-2055A, 12 pp., Series Capacitors, and GEA-1971C, 8 pp., Autotransformers for Reducing Light Flicker. General Electric Co., Schenectady.

Variac Transformers.—Bulletin, 4 pp. Describes the Variac, an auto-transformer consisting of a single winding on a toroidally-shaped core. Contact between the winding and the load circuit is made through a carbon brush which covers at least one turn of wire at all times; output voltages from the Variac are continuously variable with perfect smoothness. The device has found wide application in laboratory, research, development and production in all branches of the electrical industry. Many units are incorporated in the products of other manufacturers where smooth rotary control, low losses, and good regulation are desired. General Radio Co., 30 State St., Cambridge, Mass.